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Abstract

This book contains the papers presented at the eleventh international conference on Energy Efficiency in Domestic Appliances and Lighting, EEDAL'22 organised in Toulouse, France, on 1-3 June 2022 by the European Commission Joint Research Centre and the University of Toulouse III - . Paul Sabatier. This major international conference has been very successful in attracting an international community of stakeholders consumption (including manufacturers, consumers, governments, international organisations, academia and experts) dealing with residential appliances, equipment, metering, lighting, residential building energy consumption to discuss the progress achieved in technologies, behavioural aspects and policies, the strategies that need to be implemented to further progress this important work. Potential readers, who may benefit from this book, include researchers, engineers, policymakers, and all those who can influence the design, selection, application, and operation of electrical appliances and residential buildings.

1 Introduction

This book contains the Proceedings of the eleventh international conference on Energy Efficiency in Domestic Appliances and Lighting EEDAL'22 organised in Toulouse, France, on 1-3 June 2022 by the European Commission Joint Research Centre and the University of Toulouse III - . Paul Sabatier.. The international community of stakeholders dealing with residential equipment, metering and lighting (manufacturers, retailers, consumers, governments, utilities, international organisations and agencies, academia and experts, etc.) have already gathered ten times at the International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL) (Florence 1997, Naples 2000, Turin 2003, London 2006, Berlin 2009, Copenhagen 2011, Coimbra 2013, Lucerne 2015, Irvine 2017, Jinan, 2019). EEDAL'22 has provide a unique forum to discuss and debate the latest developments in energy and environmental impact of residential appliances and lighting, heating and cooling equipment, electronics, smart appliances, smart meters, consumer behaviour, the policies and programmes both adopted and planned, includinh their evaluation.

EEDAL will also address the technical and commercial advances in the dissemination and penetration of technologies and solutions. The three-day conference included plenary sessions where key representatives of governments and international organisations, manufacturers utilities, and academia presented their views and programmes to advance energy efficiency in residential appliances and lighting, for example, through international co-operation on product information and eco-design requirements.

Scientific parallel sessions on specific themes and topics allowed more detailed, technical and scientific presentation, in-depth discussions among participants. The EEDAL '22 conference papers presented in the scientific session included in the current Proceedings covered the following topics:

1. Policies, Standards and Labels

2. Market Surveillance and Testing

3. Focus on Developing Countries

4. Heating and Cooling

5. Buildings

6. Behaviour

7. Monitoring

8. Demand Response and Renewable Energies

9. Appliances and Lighting

2 POLICIES, STANDARDS AND LABELS

BURNT TOAST – The Case of Energy Efficiency and Labelling of Bread Toasters

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Abstract

The paper analyses the legal justification and correct targeting of EU ecodesign and energy labelling regimes – why certain appliances are regulated while others are not. This is a serious rule-of-law question.

David Coburn, a MEP for UKIP in 2014–2019, attracted significant media attention in 2016 by criticising EU interference in his breakfast menu. He claimed that EU regulations forced the manufacturers of electric toasters to reduce their capacity to such a low level that Scottish appetites would be ruined by bland, underdone toast.

Mr. Coburn's statements were undoubtedly aimed at the Brexit news market and were useful for his cause. He was incorrect in many respects. In 2016, the EU did not, and still does not, regulate the engineering of toasters on the basis of Ecodesign Directive 2009/125/EC (EDD) – or require energy efficiency labels on them.

Since 2017, energy labelling is addressed by Regulation (EU) 2017/1369 (ELR), the fourth such basic statute in four decades. EU regulation is gaining momentum and expanding: while the number of labelled appliances was eight in 1979, it will be 16 at the end of 2021. Counting pages is the classic "student's first approach" to legislation: EU energy labelling law has grown from six OJ pages in 1979 to 539 pages in 2021.

In 2014, toasters were, indeed, considered for both ecodesign and energy labelling in a preparatory study for the EU Ecodesign Working Plan 2015–2017. Its conclusions were negative, essentially for *de minimis* reasons. Market failure was not implied.

Counting toasters out, current EDD covers 32 products. All products subject to ELR are subject to EDD, but not *vice versa.* Energy labelling is mandatory for most large household appliances, such as refrigerators and washing machines.

Mr. Coburn's concerns about the EU involving itself in matters outside its remit have some merit. Both EDD and ELR now refer to *energy-related products,* while *energy-using products* were sufficient before. Ecodesign and labels could be made mandatory for any products, while allowing ubiquitous appliances like toasters to escape them.

Tasking EU legislation to venture far beyond the territory of commercial, market and traditional regulatory law is risky. The spectre of Soviet-style planned economy still looms large in much of the EU. As for toasters, there was only one model and one manufacturer in the Soviet Union, Fabrika im. V.I. Lenina in Moldovan SSR. The fixed price was 15 roubles in 1967.

Introduction

David Coburn, Member of European Parliament for the United Kingdom Independence Party (UKIP) in 2014 – 2019, attracted media attention in February 2016 by criticising undue EU interference in his breakfast menu. Mr. Coburn claimed that European Union (EU) regulations forced the manufacturers of electric bread toasters to reduce the roasting capacity of the devices to such a low level – "the power of one candle or something" –

that British, or in his particular case, Scottish, appetites would be ruined by bland, underdone slices at breakfast[1].

Mr. Coburn's statements were undoubtedly aimed at the Brexit news market and were perhaps politically productive, but they were factually incorrect in many respects. In 2016, the EU did not regulate bread toasters for their energy efficiency (EE), or require EE labelling to prove that a particular toaster conformed with certain design criteria based on the Ecodesign Directive 2009/125/EU[2] (EDD) so as to enable a CE (conformité européenne) mark on it, or require a detailed EE label attached to it, as provided by the Energy Labelling Directive 2010/30/EU (ELD)[3] in force at that time.

This situation remains unchanged in 2021, although the ELD has, in the meantime, been replaced by the new, directly applicable Energy Labelling Regulation (ELR)[4], despite new legislation on ecodesign[5] and labelling introduced in 2019 – 2021. Mr. Coburn and the United Kingdom, of course, departed the EU at the end on 2020.

Focusing on the bread toaster as an illustrative example, this article discusses the regulatory edifice built, brick by brick, by the EU for the EE of light sources and household appliances since 1992[6]. Although repeatedly considered for inclusion in the list of products subject to both ecodesign and EE labelling, the toaster has – maybe cunningly – escaped regulation again and again. As discussed in **Chapter 1**, the EU ecodesign *cum* labelling regime purports to convince both the producers and sellers and the consumers and users of energy-related products (ErPs) to choose products that consume less energy when in use, while the same energy service is achieved, consequently resulting in better energy efficiency.

Chapter 2 questions the appropriateness of an approach where only the in-use energy consumption of ErPs is accounted for. **Chapter 3** makes an excursion into the history of toast and toasting, also demonstrating that the energy service provided by the little toaster comes at a great energy cost and that, while toasters may appear primitive, even anachronistic, as household appliances, they represent a highly advanced technology – which, however, is some 100 years old. During those 100 years, toast has progressed from a delicacy to a mundane breakfast item in large parts of the world. **Chapter 4** discusses a warning example, the Mickey Mouse toaster. **Chapter 5** presents a history of EU Working Plans for EE and the position of toasters in them, and **Chapter 6** provides the conclusions.

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1 https://www.economist.com/europe/2016/10/24/the-eu-is-reviewing-the-policy-that-makes-its-appliances-so-energy-efficient.

2 Directive 2009/125/EC of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. The current, consolidated version is from 1 January 2021 and is available by means of the European Legislation Identifier (ELI) https://eur-lex.europa.eu/eli/dir/2012/27/2021-01-01.

3 Directive 2010/30/EU of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

4 Regulation (EU) 2017/1369 of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU.

5 Commission Regulation (EU) 2019/1784 of 1 October 2019 laying down ecodesign requirements for welding equipment pursuant to Directive 2009/125/EC;

Commission Regulation (EU) 2019/2020 of 1 October 2019 laying down ecodesign requirements for light sources and separate control gears pursuant to Directive 2009/125/EC and repealing Commission Regulations (EC) No 244/2009, (EC) No 245/2009 and (EU) No 1194/2012;

Commission Regulation (EU) 2019/2024 of 1 October 2019 laying down ecodesign requirements for refrigerating appliances with a direct sales function pursuant to Directive 2009/125/EC;

Commission Regulation (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009;

Commission Regulation (EU) 2021/341 of 23 February 2021 amending Regulations (EU) 2019/424, (EU) 2019/1781, (EU) 2019/2019, (EU) 2019/2020, (EU) 2019/2021, (EU) 2019/2022, (EU) 2019/2023 and (EU) 2019/2024 with regard to ecodesign requirements for servers and data storage products, electric motors and variable speed drives, refrigerating appliances, light sources and separate control gears, electronic displays, household dishwashers, household washing machines and household washer-dryers and refrigerating appliances with a direct sales function.

6 Council Directive 92/42/EEC of 21 May 1992 on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels.

1. The Objectives of Current European Ecodesign and Energy Labelling Regimes

While introducing new ecodesign regulations the EU has also updated the regime of EE labelling by means of new, amended regulations (Commission Delegated Regulations) on most major household appliances – six of them in 2019 – 2021[7]. The gap between labelled appliances and products subject to ecodesign has widened, as now there are many more "ecodesign products" which need not be labelled, such as power transformers and welding equipment. While refrigerators and freezers have been subject to EE labelling since 1994[8], now also refrigerating appliances with a direct sales function – *i.e.* refrigerators and freezers used in supermarkets and shops – are subject to labelling and require three different kinds of labels: a "general" one, another for beverage coolers and a third one for ice-cream freezers[9]. On the other hand, tyres for motor vehicles released into the Common Market have carried labels since 2012, yet there are no ecodesign requirements for them, even after the new labelling regulation for tyres took effect on 1 May 2021[10].

Electric bread toasters have, nevertheless, been considered to be included in a list of home appliances that would become subject to both the EDD and the ELD, since toasters have been scrutinised in accordance with the consecutive three-year working plans that establish indicative lists of product groups considered by the European lawmaker as priorities for the adoption of measures provided in the EDD. Implementing measures are established in Article 15 of the EDD, and the working plans in its Article 16. The first, transitional working plan, for 2009 – 2011, was adopted in 2008[11], the second, for 2015 – 2014, in 2012[12], and the third, for 2016 – 2019, in 2016[13]. The Preparatory Study for the current, fourth, Working Plan for 2020 – 2024, was completed in May 2021. The significance of the Working Plans will be discussed below in Chapter 5 of this article[14].

The Commission states in its 2016 – 2019 Working Plan[15] that the EDD has resulted "in the adoption of 28 Ecodesign Regulations, 16 Energy Labelling Delegated Regulations and 3 recognised Voluntary Agreements". The ELR, being the more recent of said two framework statutes, provides that the two working plans may be combined into one document, which probably makes practical sense. The latest Preparatory Study, which had

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7 Commission Delegated Regulation (EU) 2019/2013 of 11 March 2019 supplementing Regulation (EU) 2017/1369 with regard to energy labelling of electronic displays.

Commission Delegated Regulation (EU) 2019/2014 of 11 March 2019

supplementing Regulation (EU) 2017/ with regard to energy labelling of household washing machines and household washer-dryers.

Commission Delegated Regulation (EU) 2019/2015 of 11 March 2019 supplementing Regulation (EU) 2017/1369 with regard to energy labelling of light sources.

Commission Delegated Regulation (EU) 2019/2016 of 11 March 2019 supplementing Regulation (EU) 2017/1369 with regard to energy labelling of refrigerating appliances.

Commission Delegated Regulation (EU) 2019/2017 of 11 March 2019 supplementing Regulation (EU) 2017/1369 with regard to energy labelling of household dishwashers.

Commission Delegated Regulation (EU) 2021/340 of 17 December 2020 amending Delegated Regulations (EU) 2019/2013, (EU) 2019/2014, (EU) 2019/2015, (EU) 2019/2016, (EU) 2019/2017 and (EU) 2019/2018 with regard to energy labelling requirements for electronic displays, household washing machines and household washer-dryers, light sources, refrigerating appliances, household dishwashers, and refrigerating appliances with a direct sales function.

8 Commission Directive 94/2/EC of 21 January 1994 implementing Council Directive 92/75/EEC with regard to energy labelling of household electric refrigerators, freezers and their combinations.

9 See pp. 164 – 172 of Regulation (EU) 2019/2016, OJ L 315/155.

10 Regulation (EU) 2020/740 of 25 May 2020 on the labelling of tyres with respect to fuel efficiency and other parameters, amending Regulation (EU) 2017/1369 and repealing Regulation (EC) No 1222/2009.

11 Communication from the Commission to the Council and the European Parliament (COM(2008) 660 final), dated 21.10.2008.

12 Commission Staff Working Document (SWD(2012) 434 final), dated 7.12.2012.

13 Communication (COM(2016) 773 final), dated 30.11.2016.

14 Available at https://www.ecodesignworkingplan20-24.eu/documents (link confirmed on 1 July 2021).

15 Item 3.1, Implementing Measures Adopted – Communication COM(2016) 773 final.

not yet resulted in an actual Working Plan at the time of writing, addresses both ecodesign and energy labelling.

Consequently, energy labelling is currently mandatory in the EU for most common, large household appliances, such as refrigerators, washing machines and dishwashers, but not for small or smallish energy-using household products, from blenders and mixers to microwave ovens to sauna stoves – irrespective of their market penetration or nominal power consumption. A microwave oven, currently ubiquitous in European kitchens, can consume up to 1,000 W of electricity[16], while the wattage of a sauna stove typically lies between 2,000 W and as much as 12,000 W[17], *ca.* 8,000 W now being the typical maximum power consumption. Electric sauna stoves are, admittedly, widespread only in Finland.

2. A Bridge Too Far?

Mr. Coburn's concerns about the EU becoming involved in matters that are not within its remit are however not exaggerated. Both the EED and its predecessor Directive 2005/32/EC[18] – the 2005 Ecodesign Directive – cover not only household appliances and light bulbs but **any energy-using products ("EuPs")**, with the notable exception of "means of transport for persons or goods", (Article 1(1) and (4), 2005 Ecodesign Directive).

The wording of Article 1(1) of the current EED is even more expansive: it refers to **energy-related products ("ErPs").** Following the very basic ideas of physics, any "products", *i.e.*, **any physical objects**, can be interpreted to fall within the jurisdiction of the EDD. It is questionable whether the European lawmaker – European Parliament – ever intended the directive to project such universal scope.

Mr. Coburn's statements on toasters were soon objected to through the rather unofficial – or maybe semi-official – *Euromyths* website of the Commission, where a blog was posted in May 2016 with the title[19] ***EC has not decided to regulate toasters or kettles – and could not decide alone anyway***. The media was quick to interpret this as an admission of defeat by the Commission, exemplified by a newspaper quotation from *The Telegraph*[20]:

Brussels is temporarily pulling the plug on plans to ban high-powered kettles and toasters in order to avoid giving anti-EU campaigners fresh ammunition in the Britain's "Brexit" referendum, it was reported today.

The decision to shelve the plans until after the EU referendum comes as Brussels tries to minimise its reputation for meddling in all aspects of voters' ordinary lives ahead of the June 23 [2016] vote that will decide Britain's EU membership.

In fact only two issues were addressed in the *Euromyths* posting: that (a) no EU decision exists, and (b) if there were to be compulsory EU regulation on toasters, it would have to be adopted not by the Commission alone, but by means of a regular EU legislative process involving, among others, a Consultation Forum (Ecodesign Directive, Article 18), the Council, and European Parliament. These Commission statements were true, of course.

That said, also minor household appliances, such as toasters, have become subject to Union interest since the adoption of 2005 Ecodesign Directive. The toaster is admittedly small in size, especially when compared to major white goods, which are ecodesign-regulated and must carry EU EE labels, but a toaster consumes surprisingly much electricity. A recent market study revealed that the power consumption of a two-slice

[16] In a desktop study conducted on 16 April 2021, Gigantti Oy, which claims to be the largest retailer of home appliances and consumer electronics in Finland, offered 100 models of microwave ovens, with a typical wattage of 800 W. The maximum power rating was obviously used as a proxy for quality of the product. Link: https://www.gigantti.fi/catalog/kodinkoneet/fi_mikroaaltouuni/mikroaaltouunit. See also footnote 15 below.

[17] These assessments are based on information obtained on and from the three largest manufacturers of sauna stoves, Harvia, Helo and Narvi, which in 2018 had a combined market share of over 90 % in Finland. Links: https://saunologia.fi/suomalaiset-kiukaat/; www.harvia.fi; https://www.tylohelo.com/fi/; www.narvi.fi.

[18] Directive 2005/32/EC of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC.

[19] https://blogs.ec.europa.eu/ECintheUK/ec-has-not-decided-to-regulate-toasters-and-kettles-and-could-not-decide-alone-anyway/.

[20] https://www.telegraph.co.uk/news/12175832/Fearing-Brexit-Brussels-pulls-plug-on-kettles-ban.html.

toaster ranges from 600 W for a small, basic unit, to as much as 2,000 W[21], and even more for four-slice models. The typical wattage of an average two-slice toaster was 800 W. For all products – and not only consumer products, including light sources and household appliances – the **full life-cycle energy cost**, expanded to include mineral extraction and waste disposal, varies vastly, depending on, at least, the energy cost of

- the raw materials needed, including their transport to the manufacturing site;
- manufacturing, including packaging;
- transport to consumers (including wholesale, retail, and any middlemen);
- utilisation during product lifetime – which can vary considerably;
- transport to disposal; and
- actual disposal, including disposal of packaging.

The paradigm of law and economics requires that not only the actual cost but also the so-called transaction costs are included in the total cost of any product or utility.[22] When looking at the simplified list of events in the life of a toaster, above, it is easy to recognise that each phase in the supply chain consists of a large number smaller, long or short chains requiring commercial transactions. For example, the ores needed to produce the metal body of a toaster must be mined, refined in a smelter, combined with other metals to produce an alloy, formed into wire or sheet metal, which then is cut into suitable pieces, bent, stamped and otherwise treated to create the body of the toaster, the mechanism, filament and wiring. Each of the parties involved in the metal supply chain is usually a separate business entity, often located in separate countries. Each enterprise specialises in its own part of business. A mining company will not produce toasters, nor does it usually produce sheet metal or the various kinds of wire or filament needed.

At least a part of the toaster's body, levers and wiring are usually made of plastics, a family of materials originating from crude oil, with supply and transaction chains possibly even longer and more complicated than those for metals. Consequently, the number of transactions multiplies as the partial supply chains slowly intertwine and eventually produce the appliance offered to the consumer. When the appliance is sold, an untold energy cost – included in the multiple transaction costs – will already have been spent. None of this energy cost is accounted for in the EU EE labelling system.

Like earlier EU EE legislation, the new labelling classes adopted and enforced in 2019 – 2021 concentrate on the energy use of appliances during their utilisation phase only. They fail to pay any attention to the crucial issue of consumer transaction cost, *i.e.*, the cost resulting from the repeated times that the consumer must go into the trouble of purchasing a new appliance – a toaster, maybe – because the old one is no longer working and is not repairable at all, or not repairable at a reasonable cost. These issues are partly addressed by the newish EU Circular Economy Action Plan (CEAP), initially published by the Commission in 2015[23] and for the second time in 2020[24]. The merits of the CEAP will be discussed in another paper.

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[21] A desktop-plus-in-shop study was conducted by the author on the website of Gigantti Oy, Finland (www.gigantti.fi) and at Gigantti's Suomenoja megastore at Finnoonlaaksontie 1-5, 02270 Espoo, Finland, on 22 April 2019. At the time of the 2019 research, 78 models of toasters were available at Gigantti, with prices ranging from €16,95 to €299. The body of the cheapest 700-W-model, weighing 0,91 kg, was made of white plastic, and that of the most expensive 1,250-W-unit of painted aluminium, weighing 5 kg. Both toasters were manufactured in China.

A repeated cycle of research was conducted on 14 April 2021. Gigantti now offered 102 models of toasters, with prices ranging from €16,95 to €279, available in some 10 colours and even more colour combinations. The cheapest unit, made of white plastic, had the wattage of 750 W, and the most expensive one, made of "mint green" painted aluminium, of 1,250 W. Indeed these were the same models as in 2019.

[22] Cooter, Robert D.; Ulen, Thomas. *Law and Economics* (5th Edition). ISBN 13: 978-0-321-33634-7, pp. 91 – 95. Boston, MA. May 2007.

[23] Closing the Loop, an EU action plan for the Circular Economy. Communication from the Commission. Brussels, 2.12.2015, COM(2015) 614 final.

[24] A new Circular Economy Action Plan, for a cleaner and more competitive Europe. Communication from the Commission. Brussels, 11.3.2020, COM(2020) 98 final.

3. A Short Course in Toasters and Toasting

The household toaster is not a novelty. Various sources agree that the electric bread toaster was invented in 1893 by Alan MacMasters (1865 – 1927), a Scottish inventor[25], while Charles Perkins Strite (1878 – 1956) was issued U.S. Patent No. 1,394,450 for a "Bread-Toaster" in 1921[26]. The patented device was an automatic pop-up toaster, originally invented by Strite in 1919, similar to most toasters used today at breakfast tables all over the world. Strite's company eventually became Toastmaster – a firm whose brand is still used on toasters and other kitchen appliances sold in North America[27].

Toasted bread – *toast* – is not a novelty, either. In ***Physiologie du goût***, a classic 1825 treatise on gastronomy, **Jean Anthelme Brillat-Savarin**[28] discusses at length a luncheon which he served to his two elderly cousins at his Paris residence in 1801. The lunch – or maybe rather a brunch – started at ten o'clock in the morning with oysters and ended in the evening with transparently thin pieces of toast, carefully buttered and salted just right:

*"Je fis donc le punch, et pendant que j'y étais occupé, on exécutait des rôties (*toast*) bien minces, délicatement beurrées et salées à point."*[29].

While Brillat-Savarin described toasted bread as a delicacy worthy of a gourmand's keen attention, toast has since become one of the most common and mundane breakfast items in France, other European countries and North America. The toaster has a market penetration (diffusion) of over 90 % in Canada and the U.S. and over 70 % in most industrialised EU Member States[30]. China is the largest producer of toasters, with a market share of 73 % (2016, based on volume). The global market was valued at 1,230 million US$ in 2017, and it was estimated to reach 1,420 million US$ by the end of 2025, expected to grow at a compound annual growth rate (CAGR) of 1.8 % during 2018 – 2025[31].

As both patent history and Mr. Coburn's intervention testify, breakfast tables with bread-toasters and toasted bread are first and foremost an Anglo-American phenomenon. The market penetration of toasters is between 90 % and 100 % in the United States and Canada, as it is well over 50 %[32] in large industrialised EU Member States. The toaster has not only become through-and-through commoditised as a standard home appliance, but the appliance and its basic utility can now be purchased for what would have been some 49 ¢ in 1939[33].

It is claimed that the electric toaster's success story is due to the unparalleled convenience and utility that the automatic pop-up mechanism offers, transforming even the plainest industrial pre-sliced white bread into something crunchy and delectable, and doing it quickly, without almost any cooking skills. Indeed the increasing popularity of pre-sliced white wheat bread packaged in plastic bags, epitomised by Wonder Bread[34] in North America, very much coincided with the ubiquity of the household electric toaster.

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[25] https://pdfpiw.uspto.gov/.piw?Docid=1394450&idkey=NONE&homeurl=%252F%252Fpatft.uspto.gov%252Fnetahtml%252FPTO%252Fpatimg.htm.

[26] https://www.uspto.gov/about-us/news-updates/patent-bread-toaster-issued-october-18-1921.

[27] For example, on 12 April 2021, a Toastmaster two-slice plastic-body toaster was available in black for US$24.99 (€20.99) at Kohl's; https://www.kohls.com/product/prd-3779508/toastmaster-2-slice-toaster.jsp?prdPV=6.

[28] Brillat Savarin (1755 – 1826) was a French politician and lawyer, who is often considered the father of modern gastronomic writing. See 1911 Encyclopædia Britannica/Brillat-Savarin, Anthelme.

[29] Project Gutenberg, E-Book No. 22741, p. 354. Release date 23.9.2007, http://www.gutenberg.org/ebooks/22741

[30] Toaster Market Report by HA Factory, an Italian industry organisation for home appliances and component suppliers, from 2017, see https://www.hafactory.it/2017/12/19/the-toaster-market-2/

[31] https://www.decisiondatabases.com/ip/9970-toaster-industry-market-report.

[32] See the HA Factory Toaster Market Report, above.

[33] The CPI and the inflation calculator published by the Federal Reserve Bank of Minneapolis have been used. The reference price for today's toaster is US$9.90.

[34] https://en.wikipedia.org/wiki/Wonder_Bread. On 12 April 2021, a standard, "classic" 20-oz loaf of sliced Wonder Bread cost US$2.58 (€2.17) at Walmart's store on 1919 Davis St., 94577 San Leandro, California, USA; https://www.walmart.com/ip/Wonder-Bread-Classic-White-20-oz/37858875.

Another invention that helped to industrialise bread-baking – and indirectly breakfast-taking – was the automated bread-slicer invented in 1927 by Otto Rohwedder, an American inventor who trained as jeweller and optometrist[35]. The device, which not only sliced bread but also packaged it, was a significant commercial success, with machines soon sold to bakeries, and sliced bread to consumers, throughout the United States[36]. The toaster is now so much part of everyday experience in many Western countries that one manufacturer has chosen to call its products the *Daily Collection* and another *Love Your Day*, as witnessed by the study conducted at Gigantti by the author and referred to above.

Browsing the Internet, it is still possible to find a brand-new toaster for less than €10 – typically €9,50 or €9,90. In his book ***The Toaster Project***, Thomas Thwaites describes his 2008 quest to construct a working toaster from scratch, using a two-slice automatic Argos Value Range device as a reference model[37]. The toaster – the cheapest in the UK market at the time – contained 157 separate parts, some of which themselves were subassemblies, and it cost him £3.94 (£5.38 = €4.52 today)[38]. Currently, a similar, lowest-price model sold by Argos, costs £9.99 (€11.52) and has the power rating of 800 W[39]. The toaster project took Thwaites nine months, and his problems started with excavating and melting copper and iron. The handmade end product did not work.

To approach toasting from another individualistic point of view, a recent Swedish toaster project should be discussed briefly. In 2015, Nathan Grossman of Stockholm Academy of Dramatic Arts[40] asked cyclist Robert Förstemann, a German Olympic medal-winner (bronze, men's team sprint in London, 2012)[41] to act as a human dynamo to power a basic 700 W toaster, with one slice in, an "entry-level" model much like the one used by Thwaites. The slice produced by Förstemann's less-than-three-minute effort was deemed edible – although rather bland – but the Olympian himself physically collapsed at the end of the exercise[42]. Similar tests had been done before with Swedish athletes, without success[43].

Household bread-toasters have been available in major home appliance markets for over a century. As, *e.g.*, the exhibits of the Toaster Museum in the aptly named city of Essen, Germany[44] show, during the past 100 years, the power rating (wattage) of toasters has increased significantly, from typically 450 – 500 W to at least 600 – 700 W and up to 2,000 W, and more, today. As concerns retail prices, a state-of-the-art 1,100 W Toastmaster (model 1B9 or similar, automatic, pop-up, for two slices) cost US$16 in 1939[45], 20 years after the concept was invented, or *ca.* US$294 in 2019 dollars[46], *i.e.*, *ca.* €262[47].

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[35] U.S. Patent No. US1867377A, for a *Machine for slicing an entire loaf of bread at a single operation*, an invention made by Otto Frederick Rohwedder, filed on 26 Nov. 1928 and granted on 12 July 1932.

[36] https://en.wikipedia.org/wiki/Sliced_bread. Retrieved on 7 July 2020.

[37] Thwaites, Thomas. *The Toaster Project: Or a Heroic Attempt to Build a Simple Electric Appliance from Scratch.* Princeton Architectural Press, Hudson, NY, USA, 2011. ISBN: 97-815-6898-9976. Can be ordered from the publisher.

[38] The inflation calculator of the Bank of England has been used. See https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator, and for the currency conversion, the reference exchange rate of the European Central Bank (ECB) on 14 April 2021 has been used.

[39] See: https://www.argos.co.uk/product/9167009?clickSR=slp:term:2%20slice%20toaster:2:4:1.

The ECB reference exchange rate on 14 April 2021 has been used. Please note that the inflation-adjusted retail price of an "entry-level" white plastic toaster has more than doubled in terms of both the euro and the pound sterling in just 13 years!

[40] Reference to a written dissertation does not seem to exist.

[41] https://www.olympic.org/robert-forstemann.

[42] For a university video clip demonstrating the experiment, please see https://www.uniartsplay.se/the-toaster-challenge.

[43] http://www.dailymail.co.uk/news/article-3112063/Can-Olympic-cyclist-power-toaster-Science-experiment-shows-energy-REALLY-takes-make-simple-slice-toast.html#ixzz4pYleUp8O.

[44] http://www.toastermuseum.com/.

[45] According to an advertisement in the Washington, D.C., *Evening Star*, p. A-14, on 17 December 1939, available on the Library of Congress Chronicling America site, at

https://chroniclingamerica.loc.gov/lccn/sn83045462/1939-12-17/ed-1/seq-14/#date1=1939&index=1&rows=20&words=automatic+Toasters+Toastmaster&searchType=basic&sequence=0&state=&date2=1939&proxtext=%22Toastmaster+Automatic+Toaster%22&y=0&x=0&dateFilterType=yearRange&page=1

[46] The prices in US dollars have been adjusted with the help of the Consumer Price Index (CPI) and the inflation calculator published by the Federal Reserve Bank of Minneapolis, see https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator. The conversion into euro has been done using the

Basic toaster technology has not changed in over 100 years, from 1919, when Charles Strite was granted the basic patent for the pop-up toaster. As Thomas Thwaites demonstrated in his book, albeit with tongue in cheek, the four main components of a modern toaster are

- flat sheets of mica (pressed plates of pulverised silicates, such as muscovite);

- filament made of electricity-resistant nickel-chromium, nickel-copper or similar metal alloy, such as nichrome[48], constantan[49] or Kanthal® [50], which is wound around the mica sheets and generates heat that browns the bread by means of the Maillard reaction, named after the French physician and chemist Louis-Camille Maillard (1878 – 1936), who was the first to describe the reaction. The Maillard reaction, or rather a series of reactions, start well below the temperature of 100 °C (212 °F) and need to reach *ca.* 155 °C (310 °F)[51], so as to achieve sufficient browning of food – with many improvements in food taste and consistency occurring simultaneously;

- a spring mechanism that causes the bread slices to pop up (extrude) when the interior of the toaster reaches a certain temperature – this temperature can usually be adjusted by a lever or controller, thereby also managing the "done-ness" or the rate of browning of the bread; and, of course;

- the toaster body – consisting of a top with 1 – 6 slots, four sides and a bottom – which are usually made of metal or plastic or a combination thereof – sometimes also glass is used; the Toaster Museum has exhibits with porcelain and even wooden parts.

Since Strite's original patent, at least 1,900 patents have been granted worldwide for apparatus called "bread toaster"[52]. For most toaster-related patents, protection has expired, including the original nichrome patent for "Electric Resistance Element" made of an alloy of nickel and chrome (U.S. Patent No. 811,858, granted in 1906 and expired in 1923)[53].

Broadly speaking: in 100 years, toaster

1. retail prices have fallen to **one tenth (1/10)** or less;
2. rated **power consumption** has approximately **doubled**;
3. **market penetration has reached 100 %** in many developed Western countries;

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[47] ECB Reference Rate on 31 December 2019 (€1.1234 = US$1).

[48] U.S. Patent No. 853,891, filed on 17 January 1907 and granted on 14 May 1907, to Albert L. Marsh, of Lake Bluff, Illinois, for an "Electric resistance element". Nichrome, which originally contained the Pareto-optimally (80-20) proportioned elements of nickel (Ni) and chromium (Cr), has subsequently become commoditised, with intellectual protection property rights extending to neither the original, patented invention nor the name, which has no trade-mark protection.

[49] Constantan, an alloy of copper and nickel (cupronickel) is now commoditised, as is its name. Source: https://www.merriam-webster.com/dictionary/constantan.

[50] Kanthal® is a brand (registered trademark) for products and services in the area of industrial heating technology and resistance materials and is part of the Swedish Sandvik Group. The original Fe-Cr-Al alloy was invented in 1931 by Hans von Kantzow, a mining engineer from Hallstahammar, Sweden. The discovery was made almost by accident when a sample was forgotten in a furnace. Source: https://www.kanthal.com/en/ about-us/kanthal-award/why-kanthal-award/.

[51] The Maillard reaction, or actually a sequence of reactions, has been thoroughly researched since Maillard demonstrated the reaction in 1912. A general overview can be found through Wikipedia, at https://en.wikipedia.org/wiki/Maillard_reaction - :~:text= The%20Maillard%20reaction%20(%2Fma%C9%AA,browned%20food%20its%20distinctive%20flavor.&text=This%20reaction%20is%20the%20basis,carcinogen%20called%20acrylamide%20can%20form.

[52] For an elementary Google Patents search, https://patents.google.com/?q=%22Bread+

Toaster%22&oq=%22Bread+Toaster%22. The search for this paper was done on 9 July 2021.

[53] Nursten, H. E. *The Maillard Reaction: Chemistry, Biochemistry and Implications*, London, Royal Society of Chemistry, 2005. ISBN 0854049649, 9780854049646**.**

4. core technical solutions have **not developed any further**;

5. **patent protection** has expired for the original inventions, yet no new paradigms have emerged.

This indicates that as a household consumer product the toaster has become through and through commoditised. The same basic utility is offered by a device costing less than €10 and another priced at €300. Manufacturers and sellers differentiate their products by design features: body material, colour, form and design – outer appearance, "looks" or "optics" in general – and of course branding. Many considerations, including energy efficiency, are put aside completely, indeed to the extent that ecodesign assessment and energy efficiency labelling are not at all, with a few exceptions, available for toasters.

A notable exception, the one toaster which has been granted an *ecolabel*, the German national Blue Angel label[54], is the rather expensive Ritter Volcano, offered in three parallel models: two tabletop (3 and 5) models and one drawer-installed ET10 model, priced at the time of research between €130 and €250 on randomly chosen mail order retail websites[55]. The boxy devices, which are made in Germany, as the manufacturer repeatedly emphasises[56], seem to not be widely available from retailers outside Germany. The Bavarian company, in business since 1905, specialises in niche products, such as small built-in kitchen appliances (*"Einbaugeräte"*) including toasters and a few other appliances, which are permanently inserted in the drawers of kitchen cabinetry[57]. It appears that there is no or little competition in this sub-segment market in Europe – or indeed worldwide.

Another exception is – or rather was – a model sold under the British brand Morphy Richards, introduced in the UK market in 2008. The Ecolectric 44943 toaster, rated at 1,100 W, had a few features not common with the vast majority of competing models, then and now, in that (a) there was a layer of insulation between its heating units and the body and (b) it had a lid that closed during operation. The manufacturer claimed that an energy saving of 34 % was achieved[58]. Reasons for the withdrawal of this eco-toaster have not been disclosed, and the supplier failed to respond to inquiries.

Starting from the 2010s, many suppliers of toasters have embraced, with abandon, the idea of the kitchen as a home decoration exercise. The outer appearance – design, looks, "optics" – of almost any home appliance is and has of course always been a significant issue for household consumers, but very recently the number of colours available for small appliances, including toasters, has exploded. An example: the 75-year-old British manufacturer Dualit Ltd. published a total of 83 distinct toaster models in its 2020 product catalogue[59]. For example, the Classic two- and four-slot toasters were available in seventeen (17) colours, including "eucalyptus", "glacier blue" and "petal pink". For the rather expensive – from ca. £120 (€140) to over £300 (€350)[60] for four- to six-slot models – prominently advertised as "hand-made in England", few pretentions were made for EE, except that some models could be operated one, two and three slots at a time, whereby an energy saving was claimed.

The use and abuse of the prefix ***eco*** (or *eko, öko, øko, οικο* etc., depending on language) should be briefly discussed. The prefix is commonly used as shorthand for *ecological, ecology, ecosystem* or almost anything *ecology*-related, where the word itself is defined initially – by the Merriam-Webster Dictionary – as "a branch of science concerned with the interrelationship of organisms and their environments"[61]. In modern marketing, the meaning of *eco-* and *ecological* has been expanded to indicate anything "ecologically beneficial" or, more simply, anything good for the environment. While the incorrect and irresponsible overuse of the term is often derided as "greenwashing", there is not much to be done, at least from the point of view of current commercial and consumer protection legislation in many if not most EU MS. It would be difficult for the

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[54] https://www.blauer-engel.de/en/products/electric-devices/toasters

[55] Date of research: 10 May 2021. https://www.alternate.de/ritter/volcano-5-Toaster/html/

product/1476446?partner=DeIdealo&campaign=Toaster/ritter/1476446&utm_source=idealoDe&utm_medium=referral&utm_campaign=deidealo&utm_term=1476446.

[56] https://www.de/wir-ueber-uns

[57] https://www.ritterwerk.de/einbau-toaster

[58] See the owner's manual of the Morphy Richards Ecolectric toaster at https://www.morphyrichards.co.uk/Pdf/IB44943.pdf.

[59] See https://issuu.com/d3rltd/docs/dualit_brochure-2020-issuu, p. 28.

[60] The ECB exchange rate on 19 July 2021 is used. The approximate prices were obtained from the site Amazon.co.uk, which provides information for several competing sellers.

[61] https://www.merriam-webster.com/dictionary/. *Eco* is derived, through Latin, from classic Greek *οικοσ* [*oikos*], meaning a house or household**.**

competent regulatory authorities to interfere in cases where the green colour or wholesome country landscapes are used prominently to market practically any consumer goods, and indeed the prefix *eco* seems to have become fair game for anyone to hunt, as they obviously cannot enjoy any kind of intelle ctual property protection. A random Google search for *eco-* and *eco** returned *ca.* **1,350 million hits**[62]. While the road to greenwashing would be open for toaster-makers, beyond the above-mentioned Ecolectric 44943 toaster, there seem to have been very few other devices with *eco* inserted in their names or brands in the EU 28 market, and in these cases, ecology has referred to the option of using just one slot when one piece of bread is toasted, and not heat up the entire unit, as discussed above.

4. The Mickey Mouse Toaster Case

Before returning to Mr. Coburn, EU ecodesign and energy labelling, and understanding that entrepreneurs in the toaster business have a legitimate interest in wanting to identify new ways to differentiate their appliances from the "value line" (read: cheap) basic products that are 100 % based on 100-year-old technical solutions, to products that better appeal to consumers' brand loyalty, taste, and other elevated instincts, a potentially warning example should be brought up – the Mickey Mouse toaster.

Figure 1. A Mickey Mouse Toaster.

Mickey Mouse toasters are standard two-slot pop-up toasters depicting the well-known Walt Disney comic book character on the body and **roasting a silhouette of Mickey** on the bread slices. Two models, both manufactured in China and both targeted at the North American market, are discussed. While the "classic" model DCM-21 has a body made of red plastic and is available from many North American sources at the time of writing, the VillaWare Model V5555-11, which is made of chrome-plated steel and also plays the Mickey Mouse March[63] when toast is ready, seems to have become a "vintage" or "collectors' item" at least in the EU internal market.

At least one explanation for the unavailability of Mickey Mouse toasters in the EU Common Market is that the equivalent of Model V5555-11 was withdrawn from the Common Market after Ariete, the Italian company responsible for placing the model in the European market, voluntarily withdrew the product. The toaster was

[62] Search done on 18 July 2021. Both *eco-* and *eco** returned the same result.

[63] For a classic rendition of the Mickey Mouse March, please see and listen to https://www.youtube.com/watch?v=qmn4zO6JfPo. The song was written by Mickey Mouse Club television host Jimmie Dodd (1910 – 1964) in 1955. See the Disney Wiki at https://disney.fandom.com/wiki/Mickey_Mouse_March.

found non-compliant with the Low Voltage Directive (LVD – 2014/35/EU), risking electric shock and burns because the internal wires of the unit could come to contact with burrs, also inside the body, and damage its insulation, potentially causing a fire.

Furthermore, the notice issued on the European Commission's Rapid Alert System for Non-Food Products – with the rather unfortunately formulated acronym RAPEX[64] – categorised the non-compliance case and alert as **serious**, and pointed out that the "appliance appeals to children". The Mickey Mouse toaster incident – although certainly not the only case when toasters have been found non-compliant with the LVD and its predecessors – indicates at least the following:

- the product was of such low technical quality that it was unsafe for home use;
- the product was aimed at small children by adding non-essential features, possibly at the cost of safety, and inviting children to confuse having breakfast with playing – indeed confusing an electrical household appliance with a toy;
- technical innovation has, in the case of toasters, come to a close when products like the Mickey Mouse toaster are attracted to the market, instead of products that can actually advance technology, including energy efficiency.

5. Toasters, Ecodesign Working Plans and EU Labelling

The starting point of this paper was the question, raised by David Coburn in 2016, of the advisability of EU EE regulation for bread toasters. The issue was brought up in a preparatory study to establish the EU Ecodesign Working Plan 2015 – 2017, implementing Directive 2009/125/EC, which was requested by the Commission's Directorate-General for Enterprise and Industry (DG ENTR) and published in early 2015[65]. The preparatory study eventually resulted in the Third Ecodesign Working Plan for 2016 – 2019.

At the time of writing, August 2021, the Fourth Ecodesign Working Plan covering now directly – and not just indirectly – also EE labelling, was under preparation, with a four-volume Preparatory Study published in May 2021.

Figure 2. EU Ecodesign and Energy Labelling Working Plans

EU Ecodesign and Energy Labelling Working Plans – Toasters?						
No.	**Designation**	**Time Period**	**Published**	**Number**	**Preparatory Study**	**Toasters In?**
1	Transitional period	2005 – 2009	None identified	N/A	N/A	N/A

[64] https://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/alerts/?event=viewProduct&reference=0319/08&lngen.

[65] European Commission, Directorate-General for Enterprise and Industry

Preparatory Study to establish the Ecodesign Working Plan 2015-2017 implementing Directive 2009/125/EC, Task 3 Final Report. Brussels, 2015.

2	First	2009 – 2011	21.10.2008	COM(2008) 660 final	One document **424 pp.**[66]	**Yes** (PS)
3	Second	2012 – 2014	7.12.2012	SWD(2012) 434 final	4 volumes **513 pp.+ tables**[67]	**Yes** (PS)
4	Third	2016 – 2019	30.11.2016	COM(2016) 773 final	4 volumes + ES **708 pp.**[68]	**Yes** (PS)
5	Fourth	2020 – 2024	3rd quarter 2021	Not yet available	4 volumes **871 pp.**[69]	**Yes** (PS), in the long list
ES = Executive Summary			**PS = Preparatory Study**			**N/A = Not Applicable**

It is important to notice that electric bread toasters are mentioned in all four Preparatory Studies published so far. At the same time, only the Preparatory Study for the 2016 – 2019[70] Ecodesign Working Plan discusses the inclusion of toasters into the list of products subject to ecodesign requirements and eventual EE labelling. Toasters are identified in the Final Report, Conclusions on Task 2, in the lists of products to be considered[71], then described and discussed in Task 3 Final Report[72], and finally analysed in detail in Task 4, on nine pages of the Report[73].

The Task 4 Final Report for 2016 – 2019 provides, in conclusion, a final product matrix, which includes 16 product groups. The matrix indicates three ecodesign and EE labelling aspects and ranks each of them with one to three plusses (+ … +++), as follows:

- Level of confidence for energy savings estimates – toasters: ++
- Appropriateness of Ecodesign – toasters: +++
- Appropriateness of Energy Labelling – toasters: ++

[66] Study for preparing the first Working Plan of the EcoDesign Directive. Final report: 22/11/2007. Available through https://www.eup-network.de/fileadmin/user_upload/ Hintergrund/EuP-Dokumente/Studie_Arbeitsprogramm_08_01.pdf.

[67] Available through https://www.vhk.nl/research/reports.htm.

[68] Available through https://ec.europa.eu/docsroom/documents/20374?locale=fi.

[69] Available through https://www.ecodesignworkingplan20-24.eu/documents.

[70] The Preparatory Study was originally written for 2015 – 2017, but due to delays, the Working Plan was renumbered to cover the years 2016 – 2019. It is available through the website https://ec.europa.eu/docsroom/documents/20374.

[71] Preparatory Study to establish the Ecodesign Working Plan 2015 – 2017 implementing Directive 2009/125/EC, Task 2 Final Report, pp. 17, 19. European Commission, Directorate-General for Enterprise and Industry. Brussels, 10 February 2015.

[72] Preparatory Study to establish the Ecodesign Working Plan 2015 – 2017 implementing Directive 2009/125/EC, Task 3 Final Report, pp. 61 – 72. European Commission, Directorate-General for Enterprise and Industry. Brussels, 10 February 2015.

[73] Preparatory Study to establish the Ecodesign Working Plan 2015 – 2017 implementing Directive 2009/125/EC, Task 4 Final Report, pp. 63 – 71. European Commission, Directorate-General for Enterprise and Industry. Brussels, 10 February 2015.

To simplify this rather uneven ranking system, the plusses have been added up, giving domestic toasters a total of seven (7) plusses. Only hand dryers, hair dryers and electric kettles were ranked higher, with eight (8) plusses, and none with nine (9) plusses, which would have been the highest possible ranking.

All of these heat-emitting appliances rely primarily on heat resistance elements discussed above on pp. 6 – 7, and inventions made a hundred years ago. All of them typically consume 1,000 – 2,000 W of electricity, often well over 2,000 W. Ecodesign and energy labelling has not moved forward in the EU for any of these devices since February 2015, when the 2015 – 2017 Preparatory Study was published and both ecodesign and EE labelling were recommended for them.

Instead, the Preparatory Study for the Fourth Working Plan mentions and discusses such novelties as unmanned aircrafts (drones) and electric vehicle chargers. Both of these concern technologies that are at an early stage of development, with less than ten years of history behind them.

A *Long List of Product Groups and Horizontal Initiatives,* which is given as an annex to the Fourth Working Plan, provides 144 product groups and 12 horizontal initiatives[74]. The long list mentions not only electric toys, but also, "medium/large electric power generation" and "medium/large electric power transport [*sic!*] and distribution", meaning that the drafters of the Preparatory Study had been tasked, or adopted the task, to consider the ecodesign and eventual energy labelling of *e.g.* nuclear power plants and electricity transmission and distribution grids. Again, something that should perhaps best left alone by the European regulator. Long lists such as these are quite obviously a waste of time, effort and, consequently, the European taxpayer's money.

The elephant in the room – the room being the kitchen – is that both the EU and its regulatory apparatus currently seem to direct their attention and efforts to electrical appliances that are either fairly new and still developing (*e.g.*, drones[75]; passenger vehicle power chargers[76]), or have a low market penetration, which is not likely to change (*e.g.*, *sous-vide* cookers[77]; most professional kitchen appliances[78]), or have a very low power consumption (mobile telephone chargers, with a power rating of 5 W), while some obviously ubiquitous appliances, which sell by the tens of millions annually in Europe, decade after decade, are missed. These devices, which include not only toasters, but coffee machines (estimated 27.9 million units sold in the EU 27 in 2011)[79], hot-water kettles (23.4 million units in 2010)[80], and microwave ovens (1.3 million units in 2017)[81] are found not relevant enough by the regulator, despite their high peak consumption of 800 W – 2,000 W and more, several times a day, day in, day out. In this context, it should be borne in mind that the EDD indicates, in Article 15, Implementing Measures, that products subject to ecodesign should be covered by EE labelling (or by self-regulation) when they meet, *i.a.*, the criteria listed in Section (2) of Article 15:

> *(a) the product shall represent a significant volume of sales and trade, indicatively more than **200 000 units a year** within the Community according to the most recently available figures.*

Of course the refrigerator, also sold by the million in the EU market annually, consumes just up to ~100 W (from small units to the typical 200+100-litre refrigerator-freezers), and is base load running all or most of the time, whereas the typical toaster is a Miscellaneous Electric Load (MEL) consuming its maximum of 2,000 W for just a few minutes. But such peak consumption happens frequently, and it requires a strong power network that can withstand both the fairly predictable base loads and almost any number of MELs at peak. If not, tripping and dissatisfied electricity consumers will result in the least case, and catastrophic power failures will ensue in the worst.

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[74] Preparatory study for the Ecodesign and Energy Labelling Working Plan 2020 – 2024, Task 2, Identification of Product Groups and Horizontal Initiatives, Final, pp. 33 – 36. Assistance to the European Commission. Brussels, April 2021.

[75] Preparatory Study for 2015 – 2017, Task 3 Final Report, pp. 314 – 315.

[76] Preparatory Study for 2015 – 2017, Task 3 Final Report, pp. 314 – 315.

[77] Preparatory Study for 2015 – 2017, Task 3 Final Report, pp. 146 – 156.

[78] Preparatory Study for 2015 – 2017, Task 3 Final Report, pp. 52 – 145.

[79] European Commission (DG ENER) Preparatory Study for Ecodesign Requirements of EuPs (III), Lot 25, Non-Tertiary Coffee Machines, Task 2: Economic and market analysis – Final version. Brussels, July 2011.

[80] Preparatory for 2015 – 2017 implementing Directive 2009/125/EC, Task 3, referred to above, p. 73.

[81] Source: Statista, at https://www.statista.com/statistics/874664/microwave-ovens-sales-volume-europe/- :~:text=Sales volume of microwave ovens in Europe%202014%2D2017&text=In%202017%2C%20the%20sales%20volume,year%20at%201.2%20million% 20items.

6. Conclusions

The bread toaster is a small-size home appliance, a MEL, which has a history of over 100 years and which has been thoroughly commoditised, as all basic patents have expired. The engineering solutions present in the simplest low-price toasters today have not developed from those present in the early devices in the 1920s and 1930s. While the toaster was marketed as a luxury product still after the Second World War, adding LED lights and a rainbow of colours on the body has not made the current higher-priced toasters any more energy efficient.

The energy service offered by a toaster is the heating and browning of a piece of sliced bread, caused by the Maillard effect. Toasted bread was made in European and American kitchens on an open flame well before the appearance of the electric toaster, as is witnessed by Jean Anthelme Brillat-Savarin. Indeed the electrification of bread-toasting was one of the first steps in the general movement toward the electrification of household kitchens. Refrigerators, kettles, and electric stoves eventually followed. Since the early 1800s, breakfast toast has become a daily routine in large parts of the world, with electric toasters having a market penetration of over 90 % in many big national economies, and well over 50 % in most EU MS.

While becoming ubiquitous, toasters have not become more energy efficient, rather on the contrary. The plainest, cheapest "entry-level" toasters typically consume 700 – 800 W, and the larger "luxury" models in excess of 2,000 W – the equal of some ten to twenty (10 – 20) mid-size refrigerator-freezers.

Since 1992, ecodesign and EE labelling have been visible policies, advocated as early success stories of European energy transition. These policies translate into statutes that are binding on the EU MS, and in the case of Regulations, are directly applicable on all legal and natural persons within the Union. EU experience in the 1990s proved that voluntary measures, such as voluntary EE labelling, do not produce substantial, tangible results.

Toasters – along with other common MELs – rely on heat-resistant filament, coils and other elements made from nichrome and other alloys available since a hundred years ago, and have been repeatedly considered for EU ecodesign and EE labelling since 2008, with no action resulting.

Considering the large number of models offered in the European toaster market – there seem to be several hundred available[82] – attempts to produce and offer to customers units that deliver the required utility, a well-done piece of toast, with less energy, have been few. Even open or inferred greenwashing, now almost ever-present in the marketing for most consumer durables, has been low for toasters, with just a few *eco* models found. Of the ones identified in this study, most seem to have exited the market for unknown reasons.

The rescaling of EU EE labels in 2021, which deserves its own discussion, has turned the EE appearance of home appliances on display from bright green A++ to E and F in dull brown and orange. The *Dyson vs. Commission* case[83], also to be discussed separately, proved that ecodesign and EE labelling are legal norms to be taken seriously. In this situation, it would hardly constitute an outrage or improper interference in market mechanisms if the Union introduced ecodesign and EE labelling requirements for toasters, rendering practically all products available today in the lowest Classes F and G.

Opening, indeed forcing the toaster market to accept a new kind of competition would surely concentrate the manufacturers' attention to new engineering solutions, replacing the one-hundred-year old nichrome-based resistance elements by new alternatives, possibly including infrared – now available only in toaster-ovens – microwaves, ceramic and thick film heating elements. It appears that none of these technologies, even when tried, tested and offered commercially by component suppliers, are being applied to the common tabletop bread toaster.

Current toaster markets are an example of a total market failure as concerns EE. The situation is a far cry from the idea of forcing the worst-performing products out of the market. Nobody has been forced out of the toaster market, with the possible exception of the Mickey Mouse toy-toasters, yet little technical progress has taken place in 100 years. The EU consumer choice in 2022 could of course be viewed in the light of another

[82] For example, on 19 July 2021, the Finnish Gigantti web-store listed 106 products under *leivänpaahdin* (Finnish for bread-toaster), while the German Amazon.de site provided 130 products under *Brotröster*, and an astounding 419 products under *toaster*.

[83] See the Press Release of the General Court of the European Union at https://curia.europa.eu/jcms/upload/docs/application/pdf/2018-11/cp180168en.pdf.

industrial policy option: in the closed, planned economy of the Soviet Union, just one locally made toaster seems to have been available[84], a device called TOCTEP (*toster*), manufactured by Fabrika im. (*imena* – named after) V. I. Lenina in Bălți, Moldovan SSR, sold for 15 roubles in 1967[85]. Steven R. Reed, then a Moscow correspondent for United Press International, reported that Fabrika im. Lenina produced 10,000 toasters annually in 1982. However, sliding into a planned economy does not seem to be a risk facing the EU or the rest of the world, including China and Russia, today or in the near future.

The final conclusion is that, with Mr. Coburn gone and Brexit delivered, there should be no political obstacles to responding rapidly to the obvious market failure by introducing both EU ecodesign and EE labels for toasters, possibly starting with placing all currently available products in the lowest Classes F and G, which seem best suited for them. From that low level, progress in energy efficiency can move only upwards. Since there are household customers ready to pay hundreds of euros for a toaster – instead of €20 for a product that renders the same energy service, the heating and the Maillard effect on a piece of bread – many such consumers, especially the enlightened and affluent ones, would probably accept paying a higher price for improved EE instead of a choice of 17 colours on the toaster's body.

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Benefits of Energy Efficiency Appliance and Equipment Standards and Labelling Programmes: a 2021 update

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Abstract

At least 120 countries now have energy efficiency standards and labelling programmes in place or are in the process of developing them, which makes standards and labelling one of the most commonly adopted sustainable energy policy tools. But what are these programmes achieving and how significant is the contribution they are making to energy and climate policy objectives? To help answer these questions, this paper reports the findings of a global review of the impact of such programmes, which is derived from a comprehensive meta-analysis of over 250 specific programme impact assessments covering more than 60 countries from around the world.

The findings it reports address the: energy savings, reductions in greenhouse gas emissions and other pollutants, cost-benefits and a variety of co-benefits (employment creation, innovation, energy security and peak load reductions, water savings and health benefits) that have been attributed to such programmes. As such, the work that the paper reports is the most comprehensive international assessment of the achievements of such policies undertaken to date. Specifically, it covers:

- over 100 different types of products aggregated into 21 principal product groups
- electrical, gas and oil using products (excluding products involved in transportation)
- over 800 specific records on standards and labelling product impacts.

The paper summarises this research and the range of impacts reported and contextualises the findings both in terms of the scale of impacts achieved, their value proposition, past and current trends, and the relative importance of such policy measures within the broader objectives of providing decarbonised, healthy and affordable and secure energy services.

Introduction

This paper reports the findings of an extensive global meta-analysis of evaluations of the impacts of energy efficiency standards and labelling (EES&L) programmes conducted for the IEA 4E Technology Cooperation Programme [1]. While there were a range of voluntary programmes in a few countries in the 1970s and even as early as the 1960s, the first mandatory energy labelling programme for appliances and equipment was introduced in Canada in late 1978. Since then, a range of efficiency programmes such as labelling and efficiency standards (referred to as Minimum Energy Performance Standards or MEPS) have been adopted in at least 100 countries and now cover more than 60 different product types [2], [3]. Nor is the pace of adoption slackening off. The United for Efficiency programme reports that at least 120 countries now have such policies or are in the process of developing them.

While the design and coverage of EES&L programmes vary according to national circumstances, they provide the cornerstone of most national energy and climate change mitigation programmes. Typically, EES&L programmes use one or more of the following complementary tools to improve the energy efficiency performance of appliances and equipment:

- energy labels which 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) which provide a level playing field in competitive markets by removing the worst performing products without diminishing consumer choice [4].

Energy efficiency is typically defined as 'the level of service that can be produced for a given amount of energy input' (e.g., litres of refrigerator capacity / kWh of energy consumed). Increased energy efficiency typically refers to an improvement in this ratio. Energy efficiency is also referred to as the "hidden fuel" or, more recently, the "first fuel". Fundamentally, energy efficiency programmes are about productivity enhancement with benefits potentially extending across a wide range of areas including:

- economic (both at the household, business, state and national levels)
- employment
- health
- security (primarily energy security)
- environment.

Scope of the investigation

The IEA 4E commissioned two previous studies with a similar scope in 2015 and 2016:

- *Achievements of appliance energy efficiency standards and labelling programs – a global assessment*, released in September 2015 [5]
- *Achievements of Appliance Energy Efficiency Standards and Labelling Programs: A Global Assessment in 2016* [6].

These studies reviewed around 120 reports and papers specific to the topics of EES&L. The scope of the present study is limited to EES&L programmes relating to appliances and equipment in the commercial, industrial and residential sectors. Therefore, the impacts of building shell efficiency programmes were not considered within the scope, even though they also deliver considerable energy savings in many countries. Programmes that apply to vehicles and transport were also excluded. Three main types of energy efficiency programmes included are:

- programmes that imposed minimum energy performance standards (MEPS)
- comparative energy labelling programmes
- endorsement energy labelling programmes.

Predominantly, the programmes examined were mandatory; however, voluntary programmes were also considered, in particular endorsement labelling programmes, which by their nature tend to be voluntary.

The scope of the work reported in this paper builds on this previous work and has a refined focus. The scope of benefits was defined as falling into the following categories:

- energy, greenhouse gas (GHG), or demand reductions (absolute and/or compared to business as usual or similar proxy)
- rates of energy efficiency improvement (absolute and compared to business as usual or similar proxy)
- changes in appliance and equipment purchase prices following implementation of energy efficiency programme
- impact on consumer costs as a result of programme, i.e. capital and running costs
- concrete examples of industry innovation in response to S&L programs, such as the development of markets for new technology and increased industry R&D

- employment effects, including jobs created
- health impacts, such as improvements in air quality, reduced sick days or hospital visits.

The geographical scope is global, such that sources on any national or regional programme are included. While standards and labelling programmes can be found in over 100 countries, the bulk of these programmes, especially the established ones covering a wide range of product types, are located in the most developed economies.

While the project terms of reference states expressed a preference for ex-post evaluations of benefits (retrospective assessment of what was achieved after implementation), the number of high-quality ex-post evaluations identified was rather limited, even in developed economies with long running standards and labelling programmes. Ex-post evaluations were generally limited to those programmes that are longer running with good ongoing data collection strategies and a clear policy of undertaking ex post evaluations. There were many high-quality ex-ante studies (those that project future savings from prospective programme implementation), and many of these were included.

Methodology

The project methodology involved an extensive international review of the available published reports and conference papers on the topic. The previous two studies compiled data on some 120 reports and papers up to and including those published in early 2016. For this 2021 update, many leading energy efficiency experts from around the world were consulted regarding suitable studies that could be utilised as a part of the evidence base for this updated study. Wherever possible, multiple sources have been identified to support and corroborate the findings and to confirm the broad benefits of EES&L programmes.

For this update, the comprehensive global search uncovered some 290 new reports or papers that may have been potentially suitable for further analysis. All new reports (as well as existing reports from the 2015 and 2016 studies) were electronically catalogued in an online library. The key information recorded in this catalogue includes:

- Authors
- Title
- Year of publication
- Publisher/ organisation/ customer
- Web link
- Region covered
- Products covered
- Source
- Notes regarding suitability.

Each of the documents referred to the project team was reviewed carefully to assess the level of data available and the overall quality of the data. Documents with suitable data were tagged for more in-depth analysis. Where documents were not immediately suitable for in depth analysis, notes were prepared on each document regarding their suitability or otherwise.

In order to allow a more comprehensive analysis of the data from those reports with suitable quantitative data, key parameters were extracted and digitised in a Document Analysis Database, developed for the project. This allowed a large number of specific quantitative data to be compiled in a manner that enabled a more in-depth analysis by product and region. Around 80 new reports were found to contain suitable quantitative data suitable for extraction into the Document Analysis Database. In addition, around 36 of the studies identified in the 2015 and 2016 studies were also found to still be relevant and of high quality and were selected for more in-depth analysis.

In selecting published data to include, comprehensive ex-post studies were given a higher weighting, as these tend to provide the most reliable evidence 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, it should be understood that formal ex-post evaluation studies, where energy savings are estimated from a review of historical data after programme implementation, are relevantly uncommon in the published literature.

Data sources, terms, and concepts used in this paper

The tables below summarise the reports and data analysed by region, product type, sector, type of data available, nature of the evaluation type, and fuel types considered. The extremely broad extent of data inputs illustrates the truly comprehensive nature of the resulting meta-analysis of EES&L evaluations.

Table 1. Document analysis database record count by region

Region	Count
International	9
Africa	26
Asia	153
Central/South America	28
Europe	306
Middle East	0
North America	212
Oceania	98
Total	**832**

Table 2. Document analysis database record count by product meta-group

Product meta-group	Count	Notes
Domestic cold	145	
Non-ducted AC	125	excludes ducted
Central AC	7	
Motors	39	Electric
Lighting	33	
All-multiple	48	
TVs	31	
Transformers	26	distribution/utility
Water heating	36	
Heating	46	Service can be provided by ACs
Wet Products	94	washers, dryers, dishwashers, combinations
Ventilation-fan	25	

Product meta-group	Count	Notes
Cleaning	17	
Cooking	37	
Chillers	7	commercial buildings
Comm refrigeration	17	includes industrial coolrooms
Vending	15	includes refrigerated and heated
Computing	21	
Pumps	10	
Other electronics	44	other AV and office
Miscellaneous	10	

Table 3. Document analysis database record count by sector

Sector	Count
Residential	411
Commercial	78
Industrial	57
Other	12
All Sectors	274

Table 4. Document analysis database record count by energy and related parameters

Energy/ analysis parameter	Count
Energy reductions	567
Average Unit Energy Consumption (UEC)	19
Average on power (W)	2
Efficiency improvements	80
Emission reductions	47
Peak reductions	1
Energy costs reduction	10
Equipment cost reduction (nominal)	16
Equipment cost reduction (real)	39
Water reductions	3
Jobs created	2
Share of GWP in non-use phase	4
Benefit cost ratio	40

Table 5. Document analysis database record count by programme evaluation type

Evaluation type	Count
Ex ante	392
Ex post	81
Ex post+ante	174
Trends (no attribution)	181

Table 6. Document analysis database record count by fuel type

Fuel	Count
Electricity	753
Gas	28
Oil	3
Gas+oil	35
Water	1
Multiple	11
Other	1

Given the wide disparity of possible units reported for energy and related parameters, the general approach taken was to convert the reported data as far as possible into generic parameters which show percentage changes over time. For example, where an average new refrigerator energy consumption was reported as 500 kWh/year in 2000, and this fell to 400 kWh/year in 2010, then it would be entered as a 20% energy reduction over a period of 10 years. This means that, nominally, the energy consumption has been reducing at around 2% per year. When this is treated as a compound formula, it is calculated as an energy reduction of 1.84% over the 10-year period. Reporting of annual rates of change for any of the parameters allows these to be compared and contrasted across regions and over time.

In order to prepare the most in-depth analysis using the largest range of input data, the IEA 4E management team agreed with the project team that the most suitable data would normally be in the following forms:

- Annual rates for change in average new products delivered to the market: typically, these would be changes in energy consumption, energy efficiency, product attributes (as noted above). These were converted to a generic percentage rate to allow comparison across products and regions

- Changes in stock energy consumption in a specific year as a result of the EES&L programme 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 were generally required to generate a change in stock energy per annum as a result of the EES&L programme.

- 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) were generally required to generate a cumulative change in stock average energy per annum as a result of the EES&L programme. Note that this cumulative measure generates a lower apparent annual savings rate than the change in stock energy consumption in a particular year – the mathematics behind each of these parameters is explored in more detail in the following section.

- 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 (B/C) 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 fulfill their local regulatory requirements, so they were generally credible and relatively conservative.

In addition to these core parameters of interest, a number of reports covered other topics of key interest for this study, namely economic impacts, innovation, employment and health impacts.

High level energy impacts

Table 7 presents a summary of the total energy savings achieved from equipment energy efficiency standards and labelling programmes at the whole economy level as reported in studies where this information is available. The reporting year for the energy savings (the evaluation target year) often differs from one economy to another (or sometimes even for the same economy), and only some of the sources provide estimates of the BAU consumption that would have been expected without the EE policy measures being implemented. When BAU energy consumption data is provided, the savings have always been expressed as a percentage of the BAU value in the evaluation target year for consistency. As the BAU data is not always available, in the case of electricity, the savings in the target year are also reported as a percentage of the whole economy's electricity consumption in 2018.

The highest economy-wide savings as a proportion of the total energy consumption in the economies are reported for the EU and the USA. The projected EU electricity savings for 2020 are 14.9% of total EU electricity consumption in 2018 and 12.9% of the BAU consumption for 2020. The projected US electricity savings for 2020 are 15.5% of total US electricity consumption in 2018. Other economies report lower savings of between 0.3% and 5.9% of the national consumption in 2018 (noting these are for target years that can be even greater temporally distant from 2018 than 2020). There are many explanations for why this is the case:

- many of these economies have less extensive policy coverage (i.e. fewer product types are addressed by MEPS and labelling)

- the proportion of the entire national electricity consumption taken by the industrial sector (which has the least savings potential from MEPS and labelling) may be greater than is the case in the EU and US

- the policy measures may not have been in place as long as is the case in the EU and US and hence have not had had as long to influence the consumption of the product stock

- some economies may have less ambitious policy settings compared to the case in the EU and US.

Nonetheless, the EU and US have attained average electricity savings of the order of ~15% of their total economy consumption and are projected to have a higher savings share in the future. Had the same relative level of savings been achieved at the global level in 2018 it would have avoided demand for ~3560 TWh of electricity, which is almost equivalent to the amount of consumed electricity that was generated from renewable energy sources in the same year.

Table 7. Summary of EES&L energy savings at the whole economy level

Economy	Savings (TWh)	Target year a)	% of BAU in target year	BAU in target year (TWh)	% of 2018 consumption	2018 consumption (TWh)	No.of products Covered
EU-28 (Electricity) c)	699	2030	20.0%	3501	24.1%	2900	43/238
EU 28 (Fuel use in buildings) c)	1210	2030	35.2%	3435			28

Economy	Savings (TWh)	Target year a)	% of BAU in target year	BAU in target year (TWh)	% of 2018 consumption	2018 consumption (TWh)	No.of products Covered
EU-28 (Electricity) c)	433	2020	12.9%	3364	14.9%	2900	43/238
EU 28 (Fuel use in buildings) c)	678	2020	19.1%	3541			28
South Africa	5.5	2030			2.6%	210	9
USA (Electricity) e)	625	2020			15.5%	4033	73+
USA (Gas)		2020			5.0%	4878	27+
China	78.9	2020			1.2%	6453	~22
India	70	2030			5.5%	1277	27
Brazil (Procel label only) d)	21.2	2018	4.0%		4.0%	529	
Mexico	16	2015	6.5%	247	5.9%	271	4
Malaysia	0.4475	2015			0.3%	147	4
Japan						940	26
Korea f)						572	~45
Australia	17	2018			7.3%	234	~30

Notes: a) The target year is the year for which the savings are reported. b) The values reported for the number of products is only indicative, e.g. the EU has 43 MEPS and labelling regulations applicable to 27 broad product groups, but the impact evaluation reports savings for the number of product sub-categories indicated in this column, i.e. 238 distinct energy using product sub-types. c) Most historical and future data projections for the EU are based on EU-28, which includes the UK as the sources are historical and the UK was a member when the analysis was undertaken. Future data sets may show the UK separately. d) The savings values reported for Brazil are only for the voluntary Procel energy label and do not include any additional impacts from MEPS or the mandatory energy labelling programme. e) US national total electricity consumption data is taken from the US Energy Information Administration database. f) Korea means the Republic of Korea or South Korea throughout this paper. g) Other 2018 electricity consumption data generally taken from IEA Key World Energy Statistics 2020 (International Energy Agency 2020).

Emission reductions

While there are 48 entries in the database on CO_2 emissions savings, only four reported the reductions attributable to an economy's entire EES&L programme. For the USA it is estimated that MEPS will save 343 Mt CO_2 in 2020, which amounts to 7.1% of the national energy-related emissions for 2019. For Malaysia, the EES&L programme is estimated to have saved emissions of 1.73 Mt CO_2 in 2015, which equates to 0.7% of the country's total emissions in the same year. For the Republic of South Africa the EES&L programme is projected to save emissions of 6.0 Mt CO_2 in 2030, which equates to 1.3% of the country's total emissions in 2018. Lastly, for the EU, the Ecodesign and energy labelling programme is projected to save 311 Mt CO_2 in 2020, which is 10.7% of the EU's total energy-related emissions for 2019 (2904 Mt) and 7% of the EU's total CO_2 equivalent emissions from all sources for 2018 (4233 Mt CO_2). It amounts to 15% of the BAU 2020 total emissions of all the products subject to Ecodesign and labelling requirements. The emissions reductions due to current EU Ecodesign and labelling requirements are expected to be 498 Mt CO_2 in 2030, which is a 26% reduction in product-related emissions and 12% of the EU 2018 total for all sources.

The breakdown of the EU's emission reductions by end-use sector due to EES&L is shown in Table 8. From this it is clear that the residential sector accounts for the largest proportion of savings, followed by the tertiary/services sector then the industrial sector. Over time the share taken by the industrial and tertiary/services sectors is increasing which reflects that the oldest EES&L measures occur in the residential sector and those applicable to the tertiary/services and industrial sectors are newer and hence have had less time to influence the whole stock. Labelling, in particular, is far more prevalent in residential appliances and equipment due to the nature of the purchase process.

Table 8. GHG emissions reductions attributed to the EU's Ecodesign and labelling programs by end-use sector

Sector	**Emissions savings**		**Share of total emissions savings**	
	Mt CO_2	**Mt CO_2**		
	2020	**2030**	**2020**	**2030**
Residential	181	261	59%	53%
Tertiary / Services	79	144	26%	29%
Industry	31	57	10%	12%
Other	7	12	2%	2%
Transport	10	18	3%	4%
Total	**311**	**498**	**100%**	**100%**

These breakdowns are quite similar to those observed in other economies with extensive and mature programmes. For example, the USA appears to have approximately two-thirds of all savings from residential sector products and one sixth each for tertiary/commercial sector products and industrial products respectively.

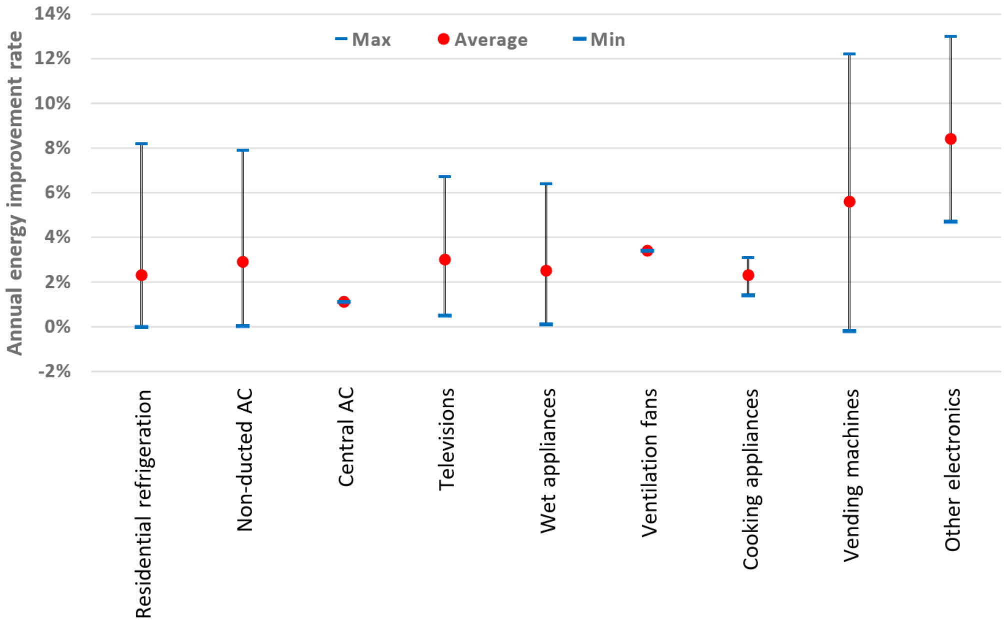
Impact of EES&L programmes on the energy consumption of specific product types

EES&L programmes typically reduce the average energy consumption of most new products around two to three times faster than similar products not covered by such programmes. The average rate of improvement varies for different products, as shown in Figure 1. 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 programmes and the frequency at which they are updated. These vary over time and between economies, which explains the ranges shown in Figure 1. The countries with the longest-running programmes 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 programmes 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 programmes recorded improvement rates of up to 8% per year.

Figure 1. Annual average reduction in new-product energy consumption from EES&L programmes



Notes: AC = air conditioning. "Wet appliances" is the category including washing machines, dryers and dishwashers. Domestic cold refers to refrigerators and freezers. Percentage improvements are calculated from a baseline which takes into account the autonomous rate of improvement in energy efficiency and separates out the specific impact of the EES&L programme. More categories are covered in the reviews of product efficiency of stock energy performance.

EES&L programmes 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 programmes on the annual rate of improvement by type of product is shown in Figure 2. 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 2. Annual reduction in stock average energy consumption from EES&L programmes

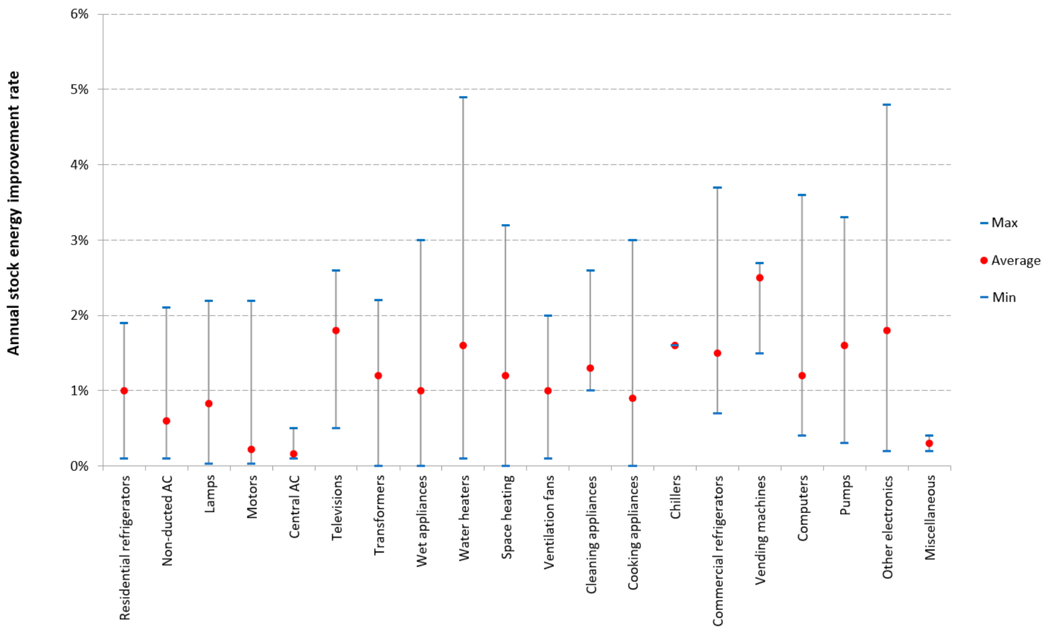
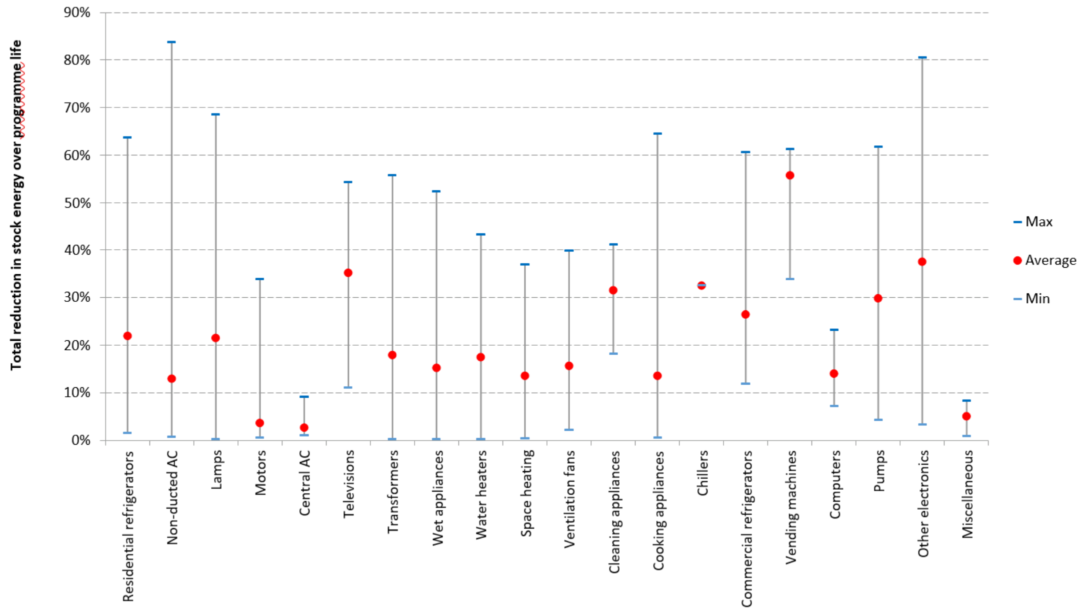


Figure 3 shows the overall energy reductions achieved by EES&L programmes over the life of the entire programme. This shows that average energy reductions between 10% and 30% have been achieved over moderate time frames for the stock of most regulated products. The savings are determined using a baseline without the EES&L programmes. 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 programmes. 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. Without these energy efficiency improvements, energy consumption from refrigerators and freezers would have been up to almost three times higher in some markets.

Figure 3. Appliance energy savings from EES&L programmes over life of programmes



Economic benefits

The assessment of economic benefits (in particular, the reduction in future energy costs, sometimes the value of reductions in emissions and calculation of net present value) is a key aspect of many EES&L evaluations. Also, the estimated equipment cost increases (noting all the attendant difficulties and uncertainties associated with this aspect) as a net present value is also often calculated. These calculations are undertaken for both the BAU case and the "with EES&L measures" case. The difference between these two cases provides an estimate of net costs and net benefits for the EES&L measure. Usually costs and benefits are summed for all years over a specified time horizon with a specified discount rate and converted to a net present value.

There are a number of ways that costs and benefits can be reported. Commonly both the net costs and net benefits (difference between BAU and "with measures") are reported in absolute values. At this point of the calculation, many countries add in administrative and programme costs to the overall cost equation. Some countries then report net overall benefits (total net benefits minus total net costs) to give a measure of absolute overall benefit from the EES&L measure. However, this measure is still in local currency units, so it is difficult to compare. To allow meaningful comparisons across different countries and regions, it is most useful to turn these parameters into a more generic indicator of cost effectiveness. The most widely used indicator is the benefit cost ratio (BCR) – total net benefits divided by total net costs. Where the benefit cost ratio is over 1.0, then the programme provides a net overall benefit. Where the benefit cost ratio is less than 1.0, the overall costs exceed the overall benefit. Many countries require a minimum threshold of benefit cost ratio for a programme to be considered cost effective. While a useful measure, it provides no indication of the magnitude of the benefits.

Many countries also undertake sensitivity analysis on the impact of different discount rates and also variations in the assumptions that go to make up overall costs and benefits. These are normal investigations, but these types of analyses have not been reported for this study.

Table 9 shows reported benefit cost ratios by economy. The reported data is the BCR value averaged across each set of products for which data is present in the database. With the exception of the EU and US data, these are not the BCR of the overall MEPS and labelling programme as the data is not weighted by the value of the benefits and costs for each product assessed.

Table 9. Benefit Cost Ratios from EES&L programmes by economy

Economy	Benefit Cost Ratio averaged over all product groups	Notes on end years, products and discounting
Canada	5.1	Mix of 2030 and 2040, all regulated products
Australia	4.5	2030 - just refrigerators
New Zealand	2.1	2030 - just refrigerators
Fiji	2.6	2030, all regulated products
Samoa	9.4	2030, all regulated products
Tonga	7.5	2030, all regulated products
Vanuatu	12.6	2030, all regulated products
Cook Islands	9.8	2030, all regulated products
Kiribati	12.5	2030, all regulated products
Japan	1.69	In 2020, 9 selected products
EU	4.7	2030, all regulated products, not discounted
USA	5.3	2050, all regulated products

Conclusions

EES&L programmes are the "quiet achiever" among energy policies, as shown by this analysis, delivering large energy and cost savings and enabling the transition to a cleaner energy future. Evidence shows that EES&L programmes can deliver annual electricity demand savings on a par with the annual production of renewable energy. Reflecting the increasing recognition of such benefits, EES&L programmes 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 programmes 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. 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 programme planning and delivery.

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

Analysis of historical changes in product prices reviewed in this study indicates that products have continued to become more energy-efficient without becoming more expensive. In addition, most programmes 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.

To encourage greater coverage and ambition the report, whose results are summarized in this paper, has provided an important expansion of the evidence set on the real benefits of existing programmes so that they can be more accurately assessed and deployed. Given their importance to the global energy system and contribution to meeting net zero targets and UN Sustainable Development Goals, it is critical that governments and research bodies move to expand this evidence to fill in gaps in terms of both new regions and the full range of benefits that EES&L programmes deliver.

References

This paper summarizes the findings from:

[1] IEA 4E TCP. Achievements of Energy Efficiency Appliance and Equipment Standards and Labelling Programs: 2021 update, June, 2021 available at: https://www.iea-4e.org/wp-content/uploads/2021/09/EESL2021_Main-Report.pdf

Note – this report presents a meta-analysis of several hundred studies and sources and a full listing of references is available within it.

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[3] CLASP 2021, 'Collaborative Labelling and Standards Program - policy database', retrieved from https://clasp.ngo/policies

[4] CLASP & Danish Low Carbon Transition Unit 2013, Energy Policy Toolkit for Energy Efficiency in Appliances, Lighting, and Equipment, Washington, DC, retrieved from https://clasp.ngo/publications/energy-policy-toolkit-for-energy-efficiency-in-appliances-lighting-andequipment

[5] International Energy Agency 4E 2015, Achievements of appliance energy efficiency standards and labelling programs, Energy Efficient End-use Equipment Annex (4E), Paris, retrieved from http://www.iea-4e.org/publications

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LAWS MATTER – The Dyson vs. Commission Cases and Their Consequences to European Energy Efficiency Law

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Abstract

This paper discusses three *Dyson* vs. *Commission* court cases pursued in the General Court and the European Court of Justice in 2013–2018. The final judgment of the General Court, adopted on 8 November 2018, upheld the original arguments of the appellant, Dyson Ltd., of Malmesbury, UK, concerning the correct measurement of energy efficiency of vacuum cleaners. The judgment annulled the Commission Delegated Regulation (EU) No. 665/2013 on energy labelling of vacuum cleaners. This is the first and only case where the European combined regime of ecodesign and mandatory energy labelling has been challenged by a manufacturer – and challenged with success.

The *Dyson* cases seem to have attracted little scientific interest, although the final judgment crushed the latest building block of the regulatory edifice constructed over forty years around Ecodesign Directive 2009/125/EC, Energy Labelling Directive 2010/30/EU, and the predecessors and successors of said Directives. Regulation 665/2013, effective since September 2014, was annulled *in toto*. In January 2019, retail stores around Europe were obliged to remove energy labels from an untold number of vacuum cleaners and their packaging, although the goods had already been released into the Common Market. Suddenly, energy efficiency regulation was seen as a folly, indeed a breach of the rule of law.

This paper sets out to discuss and analyse the following aspects of the *Dyson vs. Commission* cases:

1. The main arguments of the appellant: the necessary and sufficient conditions for winning the case. It should be noted that Dyson Ltd. was not the original inventor of the bagless vacuum cleaner, despite Dyson's advertising. A U.S. patent for a "Bagless Vacuum Cleaner" (No. 1,937,765) was filed in 1930, granted in 1933, for a W. Leathers, who worked for or with an enterprise called Quadrex Corporation. For reasons unknown, Quadrex did not become the Hoover of its time.

2. Judgment of the General Court (GC) in 2015. Dyson appealed to the European Court of Justice (ECJ).

3. Judgment of ECJ in 2017. The ECJ referred the case back to the GC.

4. Final judgment of GC in 2018.

5. Conclusions regarding

    a. EU ecodesign and energy labelling regimes. Special report No. 01/2020 of the European Court of Auditors (*"EU action on Ecodesign and Energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance"*) will be addressed in detail.

    b. relevant development of EU law in general.

6. Recommendations (*"de lege ferenda"*).

Introduction

This paper discusses three *Dyson Ltd.* vs. *European Commission* court cases pursued in the General Court and the European Court of Justice in 2013 – 2018. The dispute concerned the correct measurement of energy efficiency of vacuum cleaners and, eventually, the legality of the Commission Delegated Regulation (EU) No. 665/2013 on the energy labelling of vacuum cleaners.

Initial action relevant to the case was brought by Dyson Ltd. (Dyson), a manufacturer of vacuum cleaners and other appliances for households and public spaces, domiciled at Malmesbury, United Kingdom (UK), on 7 October 2013, and resulted in a judgment of the General Court (GC) of the European Union, of 11 November 2015 – *Dyson* vs. *Commission* (Case T-544/13), which was published in the Official Journal of the European Union (OJ), C 344, on 23 November 2015. The GC dismissed the action and ordered Dyson to pay the costs.
Dyson, having lost the case in the GC, appealed to the court of highest instance of the European Union (EU) legal system, the Court of Justice of the European Union (ECJ) under Article 56 of the Statute of the ECJ, filing an appeal on 25 January 2016. In its judgment (Judgment of the Court, Ninth Chamber, Case C-44/16 P), delivered on 11 May 2017, the ECJ ruled partially to set aside the judgment of the GC and refer the case back to it – the court of first instance.

The final, binding judgment of the GC, Case T-544/13 RENV, of 8 November 2018, upheld the original arguments of Dyson concerning the correct measurement of energy efficiency of vacuum cleaners. Most significantly, the **final judgment of the GC annulled the Commission Delegated Regulation (EU) No. 665/2013** on energy labelling of vacuum cleaners. This is the first and only case where the European combined regime on ecodesign and mandatory energy labelling has been challenged by a manufacturer – and challenged with success.

This paper sets out to discuss and analyse the *Dyson* vs. *Commission* cases – in **Chapter 1**, regarding background and the main arguments of Dyson as the original appellant. Dyson had been established in 1991 by James Dyson (b. 1947), who trained as a furniture and interior designer and, later, studied engineering. Sir James (since 2007) is a prominent public figure in the UK, a self-made billionaire who has been claimed to be the richest person in the country. **Chapter 2** discusses the first Judgment of the GC in 2015. **Chapter 3** analyses the judgment of the ECJ in 2017, whereby the ECJ referred the case back to the GC. **Chapter 4** reviews the second, final judgment of the GC in 2018. **Chapter 5** examines Special Report No. 01/2020 of the European Court of Auditors, titled *EU action on Ecodesign and Energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance*, and the relevance of the Dyson cases to the development of EU energy law. Finally, **Chapter 6** presents conclusions and recommendations (*de lege ferenda*).

It should be noted, in context with this study, that the ECJ categorically refused to disclose any documents relevant to case C-44/16 P beyond those already made public, "to any persons that are not parties to the case in question", arguing that, while the sessions of the ECJ are public, only the parties and the Court itself may have access to documents, according to the Protocol (No. 3) on the statute of the Court of Justice of the European Union and the Rules of Procedure of the ECJ.

To add insult to injury, ECJ notified that "court documents will be available only after 30 years have lapsed since the closing of the case" and then only if the regulations concerning the historic archives of the EU are adhered to, without limiting the right of the authorities to assess the justification of each request.

In view of today's situation, in 2022, seen by many as an acute climate crisis, the position of the ECJ appears to be not only counterproductive, but downright absurd.

Chapter 1 – Appellant's Main Arguments (2013)

On 7 October 2013, Dyson filed an appeal against the European Commission (Case T-544/13), asking the GC to annul the Commission Delegated Regulation 665/2013/EU (Vacuum Cleaner Regulation – VCR), which supplements the Directive 2010/30/EU (Energy Labelling Directive – ELD), with regard to energy labelling of vacuum cleaners, in its entirety, or in any event, those provisions relating to **cleaning performance and**

energy efficiency, and to order the defendant to pay its own costs and the applicant's costs in relation to these proceedings[86].

In the appeal, Dyson raised three pleas in law, alleging that

[1.] First plea in law: the Commission had exceeded its competence under Article 10 (1) of the ELR, when it adopted the delegated act in question, the VCR, as:

(a) Article 10 (1) requires that Commission delegated acts accurately inform consumers of energy consumption during use. The contested regulation misled consumers as to the vacuum cleaner's energy efficiency because cleaning performance was tested only when the vacuum cleaner had an **empty receptacle**, and not during use;

(b) Article 10 (1) requires that Commission delegated acts accurately inform consumers of essential resources consumed by an appliance during use, namely the **dust bags and filters** as consumables. The delegated act provided no such information to consumers.

[2.] Second plea in law: the Commission had violated its duty to state reasons under Article 296 of the Treaty on the Functioning of the European Union (TFEU) because the contested regulation did not explain why there was insufficient technological progress to permit testing of energy consumption and cleaning performance in a dust-loaded state. Nor was it explained why the Commission postponed dust-loading for consideration only in five years' time.

[3.] Third plea in law: the Commission had violated the fundamental principle of equality (equal treatment) by adopting a contested regulation which discriminates in favour of bagged vacuum cleaners to the **disadvantage of bagless vacuum cleaners** and vacuum cleaners based on cyclones. Loss of suction due to clogging – a feature typical of bagged vacuum cleaners during use – cannot be detected by pristine state testing. The relative merits of bagless and cyclonic technology vacuum cleaners cannot be readily identified by consumers.

The relevant provisions of the ELD, Article 10 (1), referred to by Dyson, read as follows:

(1) The Commission shall lay down details relating to the label and the fiche by means of delegated acts in accordance with Articles 11 to 13, relating to each type of product in accordance with this Article.

(2) Where a product meets the criteria listed in paragraph 2, it shall be covered by a delegated act in accordance with paragraph 4.

(3) Provisions in delegated acts regarding information provided on the label and in the fiche on the consumption of energy and other essential resources during use shall enable end-users to make better informed purchasing decisions and shall enable market surveillance authorities to verify whether products comply with the information provided.

(4) Where a delegated act lays down provisions with respect to both energy efficiency and consumption of essential resources of a product, the design and content of the label shall emphasise the energy efficiency of the product.

Article 296 of the TFEU (*ex* Article 253 of the Treaty establishing the European Community, TEC) reads as follows:

(1) Where the Treaties do not specify the type of act to be adopted, the institutions shall select it on a case-by-case basis, in compliance with the applicable procedures and with the principle of proportionality.

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86 OJ 2013/C 344/124.

(2) Legal acts shall state the reasons on which they are based and shall refer to any proposals, initiatives, recommendations, requests or opinions required by the Treaties.

(3) When considering draft legislative acts, the European Parliament and the Council shall refrain from adopting acts not provided for by the relevant legislative procedure in the area in question.

Indeed, Article 253 of TEC only contains Paragraph (2) of Article 296 of TFEU, discussing the obligation to state reasons for adopting legal acts, including Directives and Regulations, and this issue is raised in Dyson's second plea in law.

Dyson lodged an application for the case to be decided under an expedited procedure, but this application was dismissed by the Court. However, the Court decided to open an oral procedure in the case.

Chapter 2 – The First Judgment of the General Court (2015) – Case T-544/13

The GC released its Judgment on Case T-544/13 on 11 November 2015, dismissing Dyson's action in its entirety and ordering Dyson to pay the costs. The Judgment[87] quotes both the ELD and the VCR at length, then moves forward to detailed discussion of Dyson's first plea, then the third plea, and finally the second plea.

In the first part of the first plea, Dyson submitted that the VCR misleads consumers as to the energy efficiency of the vacuum cleaners, as EE measurements were made with an empty dust receptacle (dust bag), which discriminated against Dyson's bagless vacuum cleaners and other similar devices. In the second part, Dyson claimed that the VCR failed to provide information on other essential resources consumed during the use of the appliance. Such resources consist of disposable dust bags and filters made of filter paper, cardboard, plastic and possibly rubber.

Dyson's argument that the Commission had failed to accurately inform consumers of essential resources consumed by an appliance during use, especially dust bags and filters, which Dyson's vacuum cleaners do not employ at all – the GC rejected Dyson's arguments in the first part of the first plea. The Court rejected Dyson's claim that the Commission had made manifest errors of assessment, noting, also, that "the authorities of the European Union have broad discretion where their action involves political, economic and social choices and where they are called on to undertake complex assessments and evaluations" (§ 107).

In effect, the GC argued that the Commission and other EU authorities have **broad discretion** when going about their business, and that the Commission had done its work as well as it could when drafting the VCR, also taking into account future technical development.

As for the second part of the first plea – the requirement that delegated acts under the ELD accurately inform consumers of essential resources consumed by an appliance during use, namely the **dust bags and filters** as consumables, the GC took a narrow literary-formalistic short-cut by referring to the wording of Article 2, *Definitions,* part (c) of the ELD, which provides the following:

For the purpose of this Directive:

(c) 'other essential resources' means water, chemicals or any other substance consumed by a product in normal use.

The Court then argued that "[I]t cannot seriously be argued that the consumables in question, namely dust bags and filters, must be held to be water, chemicals or a substance within the meaning of Article 2(c) of Directive 2010/30" (§ 75). The rather simplistic position of the GC seems to have been that because a dust bag is not water or a chemical, it cannot be considered a substance consumed in normal use. The GC made

[87] Available on the EUR-Lex Website at https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:62013TJ0544.

this "serious" argument, although dust bags and filters are clearly consumables required for the normal use of bagged vacuum cleaners, and such dust bags are made of several substances, such as filter paper, cardboard, cellulose, plastic and rubber.

Moreover, when assessing whether dust bags and filters should be considered "other substance consumed", the broad and inclusive wording of that same Article 2, part (a), of the ELD should be borne in mind (emphasis by the author):

> *(a)'energy-related product' or 'product' means* ***any good having an impact on energy consumption during use****, which is placed on the market and/or put into service in the Union, including* ***parts intended to be incorporated into energy-related products*** *covered by this Directive which are placed on the market and/ or put into service as individual parts for end-users and of which the environmental performance can be assessed independently.*

As concerns Dyson's second plea in law, concerning the Commission's failure to state reasons under Article 296 of the TFEU, the GC simply argued that the VCR, together with its four annexes, including Annex II, *Measurement and calculation methods*, together constituted a sufficient statement of reasons, especially as the entire regime to regulate the EE of vacuum cleaners was based on a mandate established by the ELD.

As for Dyson's third plea in law, concerning equal treatment of all persons, physical and legal, who are subject to EU law, the GC made reference to EU case-law, which allows treating different situations in the same way when this is justified, based on an objective and appropriate criterion (§ 103)[88].

The Court's argumentation circled around the respective tests conducted by Dyson and the Commission with a partly loaded receptacle, and whether such tests were performed as 'circular' tests between laboratories, so that their reproducibility could be confirmed. The GC concluded that Dyson's tests did not simultaneously meet the criteria for reliability, accuracy and reproducibility. Therefore, the tests conducted in accordance with the VCR should be accepted as reliable, although the bagged and bagless vacuum cleaners tested were objectively and technically dissimilar, and the dissimilarities (dust load) may affect their EE, as even the Commission acknowledged (§§ 99 – 100).

In conclusion, the GC dismissed the action and ordered Dyson to pay the costs.

Chapter 3 – Judgment of the European Court of Justice (2017) – Case C-44/16 P

On 25 January 2016, Dyson brought an appeal, under Article 56 of the Statute of the ECJ, to the supreme instance of justice in the EU legal system. The judgment was handed down on 11 May 2017. Article 56 establishes a broad, general right for complainants to appeal, essentially just setting a two-month time limit for filing of appeals.

Dyson claimed that the ECJ should (§ 16):

- set aside GC's judgment in Case No. T-544/13 under appeal;
- annul the Vacuum Cleaner Regulation (EU) No 665/2013, which was at issue in the case; and
- order the Commission to pay the costs of all proceedings.

The Commission, opposing Dyson's claims, contended that the Court should (§ 17):

- dismiss the appeal; and
- order Dyson to pay all costs.

Dyson put forward six grounds in support of its appeal (§ 18):

[88] The GC refers to judgment in Arcelor Atlantique et Lorraine and Others, cited in paragraph 38 above, EU:C:2008:728, paragraph 47.

Firstly that the General Court mischaracterised the first plea in law put forward by Dyson at the GC;

Secondly that the GC had misinterpreted the scope of the power delegated to the Commission by Article 10 of the ELD;

Thirdly that the GC had infringed Dyson's rights of defence;

Fourthly that certain evidence had been distorted and disregarded;

Fifthly that GC's judgment failed to state reasons properly; and

Sixthly that the GC had disregarded the principle of equal treatment.

The ECJ emphasised (§ 30) that the Court Justice has no jurisdiction to establish facts or, *in principle*, to examine the evidence which the General Court accepted in support of those facts. In doing so, the ECJ wants to make itself a genuine court of appeals, which should not become involved in mundane matters like facts and evidence of facts.

However, the ECJ has allowed – and allowed in this case – an escape from this logical dead end (§ 30, *in fine*):

> *Save where the evidence adduced before the General Court has been distorted, that assessment therefore does not constitute a point of law which is subject to review by the Court of Justice,*

further referring to an ECJ judgment from 2017, Toshiba v Commission[89]. Having made an escape from the dead end, the ECJ then proceeded to overrule the GC's assessment on evidence, noting that the GC "manifestly distorted the position taken by Dyson" – referring to Dyson's evidence on reproducibility of tests and circular testing.

Consequently, the ECJ found Dyson's fourth ground of appeal – the reproducibility of testing – and the fourth part of its fifth ground of appeal – obligation for the GC to state reasons, including on the reproducibility of testing – well-founded. Dyson's arguments had prevailed!

As regards the first plea in law before the ECJ, that the General Court mischaracterised the first plea in law put forward by Dyson at the GC, the ECJ distinguished between essential elements of basic legislation, *i.e.*, those which, in order to be adopted, require political choices falling within the responsibilities of the EU legislature, and non-essential elements, making reference to Article 290 of the TFEU. The ECJ points out (§ 59) that essential rules cannot be delegated to by the EU legislator to the Commission by means such as Commission Delegated Regulations, and indeed the VCR is one of these.
The ECJ concludes (§ 68) that the Commission would have been obliged, in order not to disregard an essential element of the ELD, to adopt in the VCR a method of calculation "which makes it possible to measure the energy performance of vacuum cleaners in conditions as close as possible to actual conditions of use, requiring the vacuum cleaner's receptacle to be filled to a certain level." This did not happen, however, and consequently the ECJ established that that Dyson's first ground of appeal was well founded. Another victory for the appellant!

In the sixth ground to support its appeal, Dyson submitted that the GC had disregarded the principle of equal treatment, which is one of the fundamental principles of EU law – and indeed all legal systems of democratic nations. The ECJ argued (§ 76) that the GC had deduced "the fact that the tests advocated by the applicant do not simultaneously fulfil the criteria for reliability, accuracy and reproducibility constitutes an objective reason justifying uniform treatment of … bagged vacuum cleaners and bagless vacuum cleaners". Such uniform treatment was not equal treatment because it was "based on a finding of fact which was not validly established" by the GC (§ 77). Consequently the ECJ deemed Dyson's sixth ground as well founded.

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[89] Toshiba v Commission, C-623/15 P, not published, EU:C:2017:21, paragraph 39 and the case-law therein cited.

Finally, the ECJ ruled that it would not consider the second (misinterpretation of the scope of the power delegated to the Commission by Article 10 of the ELD) and third (infringement of Dyson's rights of defence) grounds of appeal, nor the first three parts of the fifth ground of appeal (statement of reasons), since the first, fourth and sixth ground of appeal and the fourth part of the fifth ground of appeal were sufficiently well-founded.

ECJ concluded the Judgment by

- setting aside the judgment of the GC in Case No. T-544/13 in so far as it rejected the first part of the first plea in law and the third plea in law;
- referring the case back to the GC for it to give judgment on the first part of the first plea in law and the third plea in law;
- reserving the costs, *i.e.*, ruling that the burden of costs should be decided in the final judgment.

Chapter 4 – The Second Judgment of the General Court (2019) – Case T-544/13 RENV

As the judgment of the ECJ on the Case C T-544/13 sent the dispute back to the GC, the same questions and issues returned, so to say, to the rooms of the GC, where a *renvoi* (RENV – reheard) Case T-544/13 RENV case was lodged in the summer of 2017, and the final judgment by the GC was handed down on 8 November 2018. The parties were allowed to present oral argumentation in a hearing held on 13 March 2018.

While Dyson presented as many as six main grounds for its appeal to the ECJ, Case T-544/13 RENV essentially addressed just one of them: Dyson's original first plea in law, which was lack of competence on the part of the Commission.

The ECJ had found that the GC had erred in law by failing to rule on one of the pleas in law in Dyson's application (ECJ's judgment on appeal, § 54). The GC admitted the error, accepting that it had understood that Dyson was alleging to lack of competence *per se* on the part of the Commission to adopt the VCR, whereas Dyson rather was challenging the exercise of that competence – *i.e.,* the method where the EE of bagged vacuum cleaners was calculated with empty receptacles (bags) only, stating the following:

> *The GC had, therefore, found that the first plea in law in the action essentially alleged a manifest error of assessment (judgment on appeal, § 51).*
>
> *However, according to the ECJ, it is clear beyond dispute from the application that the first plea in law in support of annulment alleges that the Commission is not competent to adopt the contested regulation (judgment on appeal, § 50).*

The above means, in essence, that because the VCR contained provisions that "disregarded an essential element of the enabling act" (§ 47) of the ELD, that being Article 10, which requires that testing methods reflect normal conditions of use (judgment on appeal, § 50), the VCR should be deemed null and void.

In §§ 78 – 82 of its *renvoi* judgment, the GC discussed the option of annulling the VCR partially or *in toto*, coming to the conclusion that the issue of proper testing is so crucial to the assessment of the EE of vacuum cleaners that **the VCR should be "annulled in its entirety"** (§ 82).

Consequently, the GC held that there was to be no need to adjudicate on Dyson's original third plea in law, equal treatment, or indeed any other claims made during the process.

As Dyson had prevailed, the GC ordered the "European Commission to pay the costs, including those relating to the proceedings on appeal before the Court of Justice." The actual amount of the costs is unknown, since the Court documents have been declared to remain secret for 30 years.

Chapter 5 – Special Report 01/2020 on Ecodesign and Energy Labelling of the European Court of Auditors

On 15 January 2020, the European Court of Auditors released a special report on ecodesign and energy labelling, publishing the findings made by its audit team in 2018 – 2019[90]. The Court of Auditors is one of the seven main European institutions, established and regulated by Part Six, Title 1, Chapter 1, Section 7 (Articles 285 – 287) of the Treaty on the Functioning of the European Union (TFEU)[91]. The Court's main duty is to examine the accounts of all revenue and expenditure of the Union[92], including those of all bodies, offices or agencies set up by the Union[93].

The Court may also, at any time, submit observations, particularly in the form of special reports, on specific questions, and deliver opinions at the request of one of the other [six] institutions of the Union[94]. The Special Report 01/2020 is such report, triggered by the adoption of a new legislative package in 2019 on ecodesign and energy labelling[95] that included, *i.a.*, new regulations on household dishwashers, refrigerating appliances, washing machines and washer-dryers, electronic displays and televisions, and electric motors[96].

The Special Report 01/2020 makes reference to the Dyson cases only once, in a footnote:

> *Case T-544/13 Dyson Ltd v European Commission, final judgment 8 November 2018. A manufacturer of bagless vacuum cleaners sought the annulment of Commission Delegated Regulation (EU) No 665/2013 on the grounds that it misled consumers about the energy efficiency of vacuum cleaners because the testing standards referred to in the regulation were not adequate. The Court annulled the regulation.*[97]

When referring to Dyson, the Court of Auditors observes "unfavourable media coverage of the policy, fuelled by attacks on perceived EU over-regulation and a well-publicised court case concerning vacuum cleaners" and notes that the "Commission decided to freeze temporarily the regulatory process in order to review the adequacy of the policy as a whole. This delayed the work on new product groups that were regarded as a priority"[98]. Since the Court of Auditors lists the Commission and two of its Directorates-General (DG ENER and DG GROW) as sources of information[99], the *prima facie* conclusion must be that public opinion has, or has had, a strong influence of EU policies regarding ecodesign and EE labelling. The entire Brexit process, which resulted in the withdrawal of the United Kingdom from the EU on 1 February 2020, was fuelled by allegations that the EU, as an organisation, and EU law, in particular, unnecessarily and irritably meddled with the daily life of Britain and ordinary Britons. Ecodesign and EE labels, which visibly brought the European flag to every UK retail outlet where home appliances – including light bulbs and other light sources – were sold, made the point clear enough.

In the Special Report 01/2020, the Court of Auditors concluded[100] that

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90 European Court of Auditors: *Special Report, EU action on Ecodesign and Energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance*, available in 23 EU languages at https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=52828.

91 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12012E%2FTXT

92 TFEU, Article 287 (1) 1.

93 *Ibid.*

94 TFEU, Article 287 (4) 2.

95 https://ec.europa.eu/commission/presscorner/detail/en/IP_19_5895

96 See https://energy.ec.europa.eu/topics/energy-efficiency/energy-label-and-ecodesign/list-energy-efficient-products-regulations-product-group_en.

97 Footnote 18 to Item 30, p. 17 of the Special Report.

98 Item 30, p. 17 of the Special Report.

99 Item 22, p. 15 of the Special Report.

100 Items 74 – 77, p. 38 of the Special Report.

- EU actions had **contributed effectively** to reaching the objectives of the ecodesign and EE labelling policies;

- effectiveness of ecodesign and labelling measures was **reduced by significant delays**, and by

- non-compliance by manufacturers and sellers. The Court estimated that **10 – 25 % of all appliances sold in the common market were non-compliant** with ecodesign and the energy labelling regime in 2019[101]. The Commission was unable to produce a breakdown of the products concerned;

- nevertheless, the Court found that the **implementing measures were adequate**, covering most of the products with the highest energy-saving potential, and that

- the Commission had used **sound and transparent methodologies** when selecting products that would be subject to regulation, yet

- the **regulatory process was lengthy**, delaying policy impact, so that ecodesign requirements and labelling could not keep up with technological progress;

- this was at least partly due to the Commission's policy to **adopt measures as packages**, rather than product-specific regulations after such regulations have been completed, which slows down the implementation, assessment and verification of regulatory measures;

- finally, the **introduction circular economy concepts had been slow**, only present – as of 2019 – in the most recent measures and proposals.

It should be noted, of course, that circular economy has become mainstream in EU policies only rather recently, most notably with the introduction of another package of policy and legislative proposals, the new **Circular Economy Action Plan**[102] (CEAP) published in March 2020, which makes numerous references to ecodesign, EE labelling and the related directives and regulations. The CEAP discusses the need to amend existing EU law but provides rather few concrete proposals.

The Court of Auditors provided **three main recommendations**, which the Commission should implement:

1. – **Improve the regulatory process** by applying a standard approach and a standard methodological framework for including the circular economy requirements. New measures should be implemented when they are ready, instead of waiting for a the completion of a legislative package.

2. – **Improve Impact Accounting** by introducing impact accounting assumptions, including those relating to noncompliance, delays and deviations. Special attention should be directed at real-life usage;

3. – **Facilitate cooperation between Market Surveillance Authorities (MSAs)** by promoting the use of the existing EU Information and Communication System on Market Surveillance (ICSMS) and organising joint trainings and other cooperation between MSAs.

The Commission mostly accepted the Court's observations and recommendations[103], with the notable exception of recommendation 1. (c), which concerned adoption of EE measures one by one, rather than in packages, as the packages would, in the Commission's view, better "demonstrate and emphasise the overall contribution of such measures to the EU climate, energy and circular economy objectives". Furthermore, the

[101] Item 58, p. 30 of the Special Report.

[102] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A new Circular Economy Action Plan for a cleaner and more competitive Europe, COM(2020)98 final, Brussels, 11.3.2020.

[103] Replies of the Commission to the Special Report of the European Court of Auditors, available at https://www.eca.europa.eu/Lists/ECADocuments/SR20_01/SR_ Ecodesign_and_energy_labels_EN.pdf.

Court's Recommendation 2. (c) was only partially accepted by the Commission, indicating that assessing of the actual effectiveness of EE targets and progress made by the MS remains a major challenge.

Market surveillance is, by definition, most relevant in those Member States where the producers of home appliances and other equipment subject to ecodesign and EE labelling are domiciled. The very basic tenets of the common market require that once a product is designed and manufactured in a EU country, and subsequently released into the common market, it must be possible freely to move and sell such products anywhere within the EU. For example, a dishwasher made in Germany, with over 20 factories, or "manufacturing sites", for home appliances, must be directly saleable in Finland, which no longer has local manufacturing[104]. Indeed, Finland no longer has a laboratory certified to inspect the conformity of appliances, but any testing and certification must be done in Sweden or Germany[105].
Consequently, the German MSAs are busy with surveillance and verification of German-made products and must employ large organisations and staffs, while the Finnish ones don't, as they can – or should be able to – rely on the professionalism and work already done by the MSAs in Germany, France and Italy, where most European home appliances are manufactured. In February 2022, the Finnish Safety and Chemicals Agency (TUKES), which is the national MSA responsible for market surveillance of appliances, also in respect of ecodesign and EE labelling, employed four (4) civil servants to survey ecodesign and labelling in the Finnish market: two senior employees and two field inspectors. The field inspectors are tasked to search for non-compliant products, including missing energy labels, in shops throughout the country[106].

Since an increasing number of appliances is sold via the internet, the sellers have, since 2014, been required to display the equivalent of energy labels on their websites. This was achieved by Commission Delegated Regulation (EU) No. 518/2014, which amended ten Delegated Regulations covering most major appliances in the market[107]. To survey this part of sales, the Finnish MSA relies on a jointly developed Nordic IT tool called **Nordcrawl,** a system that automatically collects, or "crawls" data from the sites of sellers in the Nordic market, which, in practical terms, is no different from the Common Market[108].

As concerns the estimate of "around 10 – 25 %" of products – *i.e.*, products subject to the ecodesign and EE labelling regimes – sold in the Common Market being non-compliant in 2019, which could lead to a decrease in energy savings of some 10 %[109], it should be noted that that estimate reflects an exceptionally wide divergence, especially when it comes from an auditor. The 10 – 25 % assessment, which found its way also to the press release published by the Court of Auditors[110], seems to originate in another press release, which concerned the adoption of a new package of energy labels, published by the Commission on 11 March 2019[111]. It is very difficult to believe that a quarter of appliances were, and may still be, non-compliant. If that is true, then the much-acclaimed European ecodesign and labelling system must be failing in a pitiable way, and no redesign of the appearance of labels can help.

104 Applia, the industry organisation for home appliance manufacturers in Europe: *Report of the Home Appliance Industry in Europe 2019 – 2020*, p. 46, available at
http://statreport2019.applia-europe.eu/files/applia-statistical-report-2020.pdf

105 This information has been obtained from Ms. Marika Keskinen, Senior Inspector, who is responsible for ecodesign, energy labelling, toys and products for children at TUKES. The interview was made on 21 February 2022.

106 *Ibid.*

107 Commission Delegated Regulation (EU) No 518/2014 of 5 March 2014 amending Commission Delegated Regulations (EU) No 1059/2010, (EU) No 1060/2010, (EU) No 1061/2010, (EU) No 1062/2010, (EU) No 626/2011, (EU) No 392/2012, (EU) No 874/2012, (EU) No 665/2013, (EU) No 811/2013 and (EU) No 812/2013 with regard to labelling of energy-related products on the internet – the appliances concerned were dishwashers, refrigerators, washing machines, televisions, air conditioners, tumble dryers, light sources (lamps), vacuum cleaners, space heaters and water heaters.

108 See https://www.norden.org/en/publication/nordcrawl-2.

109 Item 58, p. 30 of the Special Report.

110 https://www.eca.europa.eu/Lists/ECADocuments/INSR20_01/INSR_Ecodesign_ and_energy_labels_EN.pdf

111 https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1596

Chapter 6 – Conclusions

The three *Dyson* vs. *Commission* cases reveal that the European regime which combines ecodesign – *i.e.,* the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle[112] – and the energy labelling of products designed in accordance with ecodesign principles – is not a system destined to exist in its own, special EE bubble.

Like all other branches and sub-branches of European Union law, the Ecodesign Directive and the Energy Labelling Directive are subject to independent legal action by citizens, companies, public entities and other parties subject to the European legal system, and, in the extreme case, scrutiny by the EU Courts.

This statement is true – more than ever before – after the GC handed down its judgment in Case T-544/13 RENV in 2018, ruling that the Commission had indeed erred in law by issuing and enforcing the VCR in 2013. As the VCR was a Commission Delegated Regulation, it was the Commission alone that was responsible for the legality of the regulation. The GC finally ruled that the VCR breached the ELD, which, as a norm, was on a higher hierarchical level than the VCR, and, since the breach – the establishment of improper testing requirements – was serious enough to be considered crucial to the assessment of the EE of vacuum cleaners and the use of energy and other essential resources during use, enabling end-users to make better informed purchasing decisions[113], the GC ordered that the VCR should be annulled in its entirety.

It should be noted that the issue of dust bags and filters, which was a major point in Dyson's original appeal (first plea in law, second part) and GC's first judgment in Case T-544/13 (§§ 71 – 76), and the issue of dust bags and filters being essential resources consumed by an appliance during use, like water and chemicals, were not at all addressed either in the ECJ Case C-44/16 P or the *renvoi* case in the GC. This is significant because the saving of resources achieved by eliminating the dust bags has always been an issue stressed by Dyson, particularly in its advertising.

Article 10 of the ELD discusses Commission Delegated Acts, such as the VCR, and points out that the delegated acts shall enable market surveillance authorities to verify whether products comply with the information provided. The European Court of Auditors discussed the role of market surveillance in its Special Report 01/2020 on Ecodesign and Energy Labelling, noting that 10 – 25 % of all appliances released to the common market could be non-compliant and recommending that the role of market surveillance authorities of EU MS should be strengthened.

Interestingly, the Court of Auditors' Special Report 01/2020 makes only one reference to the Dyson cases, observing, *i.a.*, that there had been "unfavourable media coverage of the policy, fuelled by attacks on perceived EU over-regulation and a well-publicised court case concerning vacuum cleaners". This observation hints that "unfavourable media coverage" may have influenced the outcome of the Dyson court cases. The Court of Auditors is, of course, a court just in name, while the GC and the ECJ are traditional Courts of Law.

As for Sir James and his company Dyson, they went back to the European courts in February 2019, seeking €176 million from the Commission in compensation for significant material and non-material damage caused to Dyson's business. This Case No. T-127/19 was dismissed by the GC in December 2021, and Dyson was ordered to bear its own costs and pay the costs incurred by the Commission. Dyson has not been observed to have appealed.

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Online Energy Labeling: Regulation and Compliance in the Growing Online Market

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Abstract

Energy labels engage retailers in promoting efficiency and influence consumers to choose—and manufacturers to develop—more efficient products. To achieve this goal, labels need to be visible wherever purchasing decisions are made. With the steady growth of e-commerce, it is becoming increasingly important to require display of energy labels for energy-using products sold online. In 2015-2020, the annual rate of e-commerce growth for major appliances was estimated at 17% globally, which increased to over 25% in 2020 due to the Covid-19 pandemic. This growth is expected to continue as e-commerce capabilities improve and consumers gain confidence in online purchasing. Regulating and enforcing online energy labeling is necessary to secure market transformation as well as emissions reduction and energy conservation targets.

Few economies currently have mandatory online labeling requirements, including the European Union (EU) and United Kingdom, the United States, China, and South Africa. However, e-commerce growth is also recorded across the Asia Pacific region, North America, the Middle East, and Africa. This paper discusses the status of online regulations and enforcement mechanisms globally, including unique challenges such as regulating online retail platforms for third-party sellers. The paper provides insights and recommendations for policy makers and experts seeking to develop requirements for and increase compliance with online labeling regulations. The recommendations are informed by a case study on the EU—which has required online labels for energy-using product sales to be displayed since 2015—including lessons learned from the 2020 evaluation of online labeling compliance in the EU.

Introduction

Labeling programs that promote highly efficient energy-using products ("products")[114] are a valuable tool for consumers, industry, government energy agencies, and other institutions interested in market transformation. While minimum energy performance standards (MEPS) remove the least-efficient products from the market, credible energy labels drive product markets to higher efficiency by 1) allowing consumers to make informed purchasing decisions by differentiating high efficiency products from average and low efficiency products; 2) incentivizing the production of more efficient products by helping manufacturers market their high efficiency products with labels that provide unbiased evidence; and 3) allowing policymakers to easily identify high efficiency products to target for bulk purchasing, financing, and incentive programs.

As of 2021, approximately 95 economies had either mandatory or voluntary energy labeling programs for at least one product type [1]. To date, the labeling regulations have targeted products sold in brick-and-mortar stores[115] where products bear physical labels at the point of sale. However, with growing online appliance sales, governments are exploring regulations that require displaying energy labels for products sold online. To date, few countries have mandatory online labeling requirements globally, including the European Union (EU), the United Kingdom (UK)[116], the United States (US), China, and South Africa, while Australia, Ghana, and others are currently considering them. These regulations are key to ensuring consumers have access to the same information prior to their purchase whether they are shopping in brick-and-mortar shops or online, especially in economies with large and/or rapidly growing appliance e-commerce markets. Emerging research indicates that viewing an online label makes consumers more likely to purchase an efficient product [2] and regulations

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[114] In this paper, we use "products" to refer to various categories of energy-using products (including appliances, lighting, etc.) marketed to consumers. These products may be purchased for commercial use but are primarily used in households.

[115] "Brick-and-mortar stores" refers to establishments where consumers can physically see a product prior to purchase.

[116] The UK mirrors the EU legislation.

adopted in one economy can produce spillover benefits in others, influencing regulation of markets globally [3].

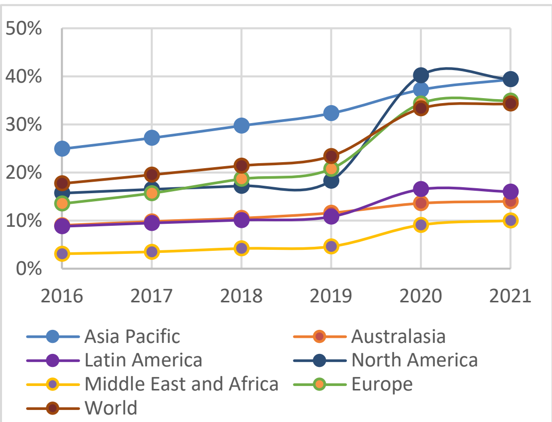
This paper discusses the status of online energy labeling ("online labeling")[117] regulations and enforcement mechanisms globally, including online appliance market trends and unique challenges to regulating and enforcing online labeling, such as regulating online retail platforms for third-party sellers. It uses the EU as a case study, informed by the quantitative and qualitative evaluation of labeling compliance on 72 online retail websites for five products in six EU member states in late 2020. The paper is intended to provide insights and recommendations for policymakers and experts seeking to develop and increase compliance with online labeling regulations.

Global Online Appliance Markets: Trends

E-commerce offers consumers competitive prices, convenience, and a large product selection. Global consumer appliance[118] e-commerce is steadily growing globally—from 18% in 2016 to 34% in 2021 (Figure 1). In the last six years, e-commerce for consumer appliances significantly grew in four regions—the Middle East and Africa (+23%), Europe (+20%), and North America (+19%)—but less so in the Asia Pacific region (+11%) where online appliance sales were already relatively high. Since early 2020, the Covid-19 pandemic has accelerated the shift to online purchasing, as consumers who would typically purchase appliances in brick-and-mortar stores transitioned to shopping online. The Asia Pacific region and North America had the highest appliance e-commerce sales rates in 2021, at 39%.

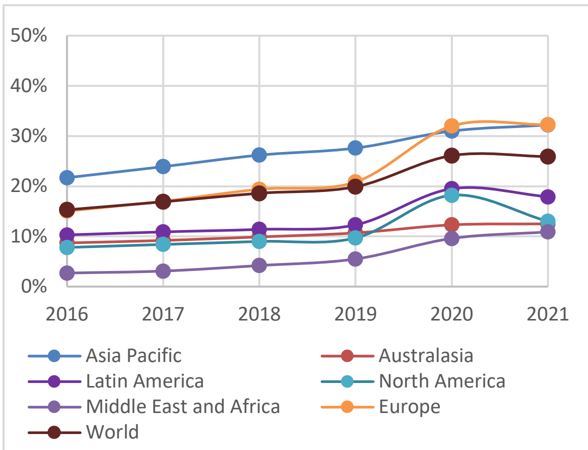
Estimated e-commerce annual growth for major appliances[119] in 2016-2019 was 7% globally. In 2020, the online sales grew by 31%, reaching 26% of global online appliance sales (Figure 2). Online sales of consumer appliances are predicted to have stabilized in 2021, levelling off from the unprecedented climb in 2020 [4]. However, appliance e-commerce is expected to continue growing as brands improve their e-commerce capabilities and consumers gain confidence in purchasing appliances online [5].

Figure 1. E-commerce Share of Consumer Appliances Sales Between 2016-2021



Source: Euromonitor International, Ltd.

Figure 2. E-commerce Share of Major Appliances Sales Between 2016-2021



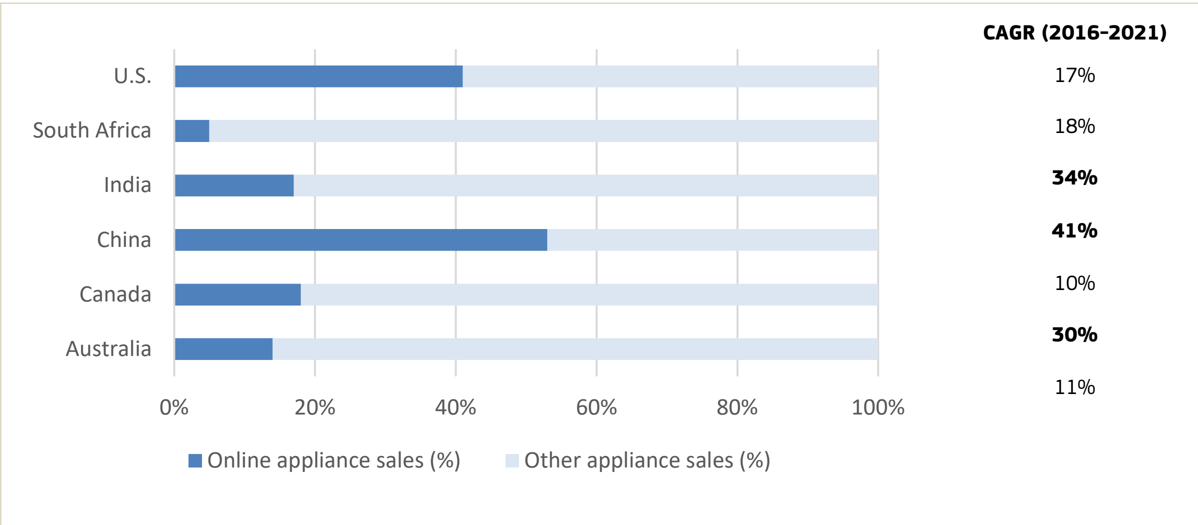
Source: Euromonitor International, Ltd.

[117] We use "online labeling" to broadly refer to any requirements under an energy labeling regulation that applies to display and/or sale of energy-using products online (e.g., requirement to provide consumers with a product information sheet).
[118] "Consumer Appliances" is an aggregate of small and major appliances including dishwashers, vacuum cleaners, and irons, as well as refrigeration, home laundry, cooking, food preparation, personal care, heating, and air treatment appliances.
[119] "Major Appliances" include dishwashers and microwaves, as well as refrigeration, home laundry, and large cooking appliances.

This paper investigates appliance e-commerce in countries that 1) have large online appliance markets, 2) have seen their online markets grow rapidly in recent years, and/or 3) have or are considering online labeling regulations. The countries of interest include the EU, China, the US, South Africa, Ghana, and Australia.[120] In 2021, 53% of consumer appliances in China are estimated to be purchased online while the US appliance market is expected to reach 41%. Both countries have high online appliances sales as consumers are accustomed to shopping online. In 2021, EU online consumer appliance sales are projected to reach 35% (Figure 3) and major appliance sales 32% (Figure 2).

Canada and India have fast-growing online markets, but they have only expressed interest in having some form of online labeling program and have yet to implement any initiatives. Appliance e-commerce had small market shares in Canada and India but showed a significant average annual growth of 30% and 41%, respectively, between 2016-2021 (Figure 3). A similar trend is seen in South Africa, where online appliance sales grew annually by 35% in the same period. Although Ghana[121] and Australia have relatively small online appliance markets, their governments are looking into opportunities to require online energy label for appliances.

Figure 3. E-commerce Projected Share of Total Online Consumer Appliances Sales in 2021 and Compound Annual Growth Rate (CAGR) from 2016-2021



Source: Euromonitor International, Ltd.

Characteristics of Online Markets

To effectively regulate online markets and develop international best practices, it is essential to understand the relative complexity of online markets compared to brick-and-mortar stores. This paper aims to help classify various e-commerce characteristics—roles (i.e., online platforms, first-party sellers, third-party sellers, suppliers), business models (i.e., online retailers, online marketplaces), and seller locations relative to consumers (i.e., local sales, international sales, local branch sales)—and discuss the regulatory implications of the complex interconnections between these characteristics.

[120] This is not an exhaustive list of the countries with online labeling requirements.
[121] No data available on online appliance sales in Ghana.

Definitions

Online sales fit under a broader category of *distance selling*, which refers to any situation where a consumer cannot physically view the exact product they are purchasing. For the purposes of this paper, we are specifically interested in the online display and sale of products, which has unique considerations compared to other forms of distance selling (e.g., ordering from a physical catalog). We do not discuss *endorsement labels* (e.g., ENERGY STAR) since the labels are voluntary.

Regarding accountability to display online labels, **the entity that puts a product model on the market for purchase by consumers** is the entity legally responsible for compliance, and therefore held accountable for non-compliance. In this paper, we define an *online platform* as the digital infrastructure through which consumers can find information about and/or purchase products (e.g., websites, advertising platforms). We define a *first-party*[122] *seller* as owning the brand of product they are selling to consumers through their own online platform and a *third-party seller* as owning and selling a product on an online marketplace. We use *seller* to refer broadly to first- and third-party sellers and *supplier* to refer to an entity from which sellers receive their products (including manufacturers). We refer to manufacturers as sellers in cases where they are selling their own products. We define an *online retailer* as when the platform owner is selling products to consumers (e.g., first-party sellers like Best Buy, Target) and an *online marketplace* as when a platform owner manages transactions for third-party sellers who sell to consumers (e.g., eBay). The lines between these terms are becoming increasingly blurred in online markets and platforms can have any mix of these characteristics. For example, in the US, the online platform Amazon.com has the characteristics of an online retailer (for sale of Amazon brand products with Amazon serving as the first-party seller) and an online marketplace (for sale of products by third-party sellers).

Resale of product units, including secondhand marketplaces, is not discussed as resale scenarios vary greatly on a case-by-case basis. Although units that are purchased new, returned to the seller unused, and re-sold as new are subject to the same labeling regulations as new product sales, performance of used products at the time of resale is unverified, which can render an energy label inaccurate.

Seller location relative to where products are sold to consumers impacts which economy's regulations apply to the sale. In this paper, we define a *local sale* as when a seller sells a product in the same economy where it is based; an *international sale*[123] as when a seller sells a product in an economy where it is neither based nor registered; and a *local branch sale* as when a seller is based in one economy but is locally registered in another economy where it sells a product. For example, any sellers based outside of the EU that wish to sell products covered by energy labeling regulations to consumers within the EU are required to have a legal representative in the EU [6]. This kind of online sale would be a local branch sale.

Although not unique to online labeling, a crucial component of regulation and enforcement is **standardized tracking of product information**, which is most efficiently achieved using a product registry. In this paper, we define a *product registry* as an official system for the mandatory registration of regulated product models[124] that enter the market and recordkeeping of product information, and a *product database* as a public facing[125] collection of registered product information that can be used for consumer awareness. Regulators can use product registries to assess compliance by verifying energy labeling information advertised for regulated products sold online. In many instances, there are hybrid product registries and product databases that are both publicly accessible and used for official registration purposes. However, public facing product databases may only include select information from the product registry deemed relevant to consumers (e.g., product specifications and performance data such as energy and/or water consumption) and consumers may not be able to access the full extent of product information in the registry. This is the case with the European Product Registry for Energy Labelling (EPREL). Registration in this database is mandatory for all regulated products, which national Market Surveillance Authorities (MSAs) can use for

[122] Traditionally, in the context of sales, "first party" is the seller, "second party" is the consumer (also known as the end-user), and "third party" is an entity contracted to provide goods or services to the consumer on behalf of the seller.

[123] International sales introduce considerations around whether an energy-using product from one country is optimized for the electrical configurations common in another country (e.g., volts, hertz, power cord plugs). This is not a common issue due to limitations platforms often set around which countries a consumer can have their purchase shipped to.

[124] Some product registries require each unit of a regulated model to be tracked. For the purposes of this paper, we only discuss product registries in the context of tracking regulated product models.

[125] A public facing product database may be accessible by web and/or mobile app. Some energy labels contain a QR code that, when scanned, directs consumers to the product's entry in a public database.

verification purposes and to facilitate compliance, while consumers can access consumer-relevant subsets of the registry data.

Challenges to Regulating and Enforcing Online Labeling

The rapid growth of e-commerce lends itself to an ever-increasing number of energy-using products being sold online, making online labeling regulation and enforcement a time sensitive effort. Key challenges to overcome include identifying webpages and websites for regulation, identifying roles and responsibilities, understanding consumer behavior, and limitations of existing online platform and enforcement agency infrastructure.

Identifying Webpages and Websites for Regulation

Whereas a consumer only sees product information in a single place in a brick-and-mortar store, they may see product information on numerous webpages within one website (e.g., product specific webpages, the shopping cart, the check-out page, website features such as product comparison or suggested products, e-catalogs[126]). Legislation for online labeling generally requires label display near the price of a product, however, each webpage and website feature has differing amounts of visual space available, as well as limitations regarding the ability to provide links to additional required information under labeling regulations (e.g., product information sheets). Beyond e-commerce websites, there are also informational websites, webpages, and even blog posts dedicated to discussing or comparing product information, as well as image and video advertisements that may appear on partner websites, video streaming services, and apps from advertising services (e.g., Google Display Network[127]). Because consumers cannot make purchases directly on these platforms, they are typically not covered by the labeling obligations. However, consumers often use this information to inform their purchasing decisions, whether purchasing online or in brick-and-mortar stores, which makes the online spaces (e.g., webpages, advertisements) where this information is displayed relevant for online labeling regulations.

Identifying Roles and Responsibilities

Suppliers have certain obligations to provide energy labeling information when they pass products on to sellers. Once the seller advertises a product to consumers, they take on responsibility for providing energy labeling information to consumers. These roles are clear in brick-and-mortar stores, where store owners are responsible for displaying the label with the physical product. However, responsibilities can be particularly complicated in online marketplaces. While the owner of an online platform must provide the infrastructure for compliance with online labeling requirements (e.g., web design for compliant label display, designated places for sellers to upload product information sheets), it is up to the third-party seller to upload required information on their listings. Platform owners are unlikely to invest in the internal processes to self-regulate without any incentive to ensure labeling compliance. Obligations of each type of stakeholder within online markets should be thoughtfully and clearly defined to prevent loopholes in regulations leading to compliance and/or enforcement issues.

E-commerce is also more complex in terms of economic jurisdiction for sellers and enforcement agencies. It must be clear which economy's requirements apply based on whether the seller is performing a local, international, or local branch sale—and which entity is responsible for ensuring product listings comply under each scenario. If a third-party seller fails to provide product labeling information in compliance with the requirements regulated by the economy of a consumer who purchases the product, it must be clear who should be held accountable for non-compliance. For example, if a product required to display the EnergyGuide

[126] Product specific webpages are where consumers can purchase a specific product; the shopping cart is where consumers can see an overview of all products they have selected for purchase; the check-out page is where consumers enter payment information; product comparison features compare the product information of multiple products on a single page; suggested products features show consumers products that may be of interest to them, often based on their browsing history on the website or what other consumers have historically opted to navigate to; e-catalogs showcase a selection of a seller's products.

[127] Google Display Network is a collection of over 2 million partner websites, videos, and apps that sellers can advertise to using the Google Ads platform.

label is sold to a US consumer on a platform operating out of a country without any online labeling regulations, no one can currently be held accountable if the sale is non-compliant with US regulations.

Regulations must also clearly identify the jurisdiction and responsibilities of enforcement agencies, as well as provide them with the authority and tools to perform these actions. This includes clearly outlining the authority of enforcement agencies, market surveillance[128] and conformity assessment[129] activities, types of offenses, and methods for deterring and responding to non-compliance. The complex nature of emerging online labeling requirements necessitates that sellers are provided the chance to correct non-compliance. Consequent enforcement actions should be designed to penalize non-compliance proportionately with the severity and impact of the offense (e.g., improper label location vs. missing label; first-time vs. repetitive non-compliance).

Understanding Consumer Behavior

The core purpose of energy labels is to help consumers identify and select—and ultimately drive the market toward—more energy efficient products. The requirements specified in online labeling regulations must balance consumer benefits with the level of administrative burden placed on platform owners. To achieve this, it is important to understand what information influences consumers' purchasing decisions, which can vary greatly between economies. This knowledge can inform what information should be featured on an online label. The information displayed can be a simplified version of the full energy label to avoid requiring platform owners to spend limited visual space to display irrelevant details to consumers. Retailers can use nested displays[130] to showcase simplified information, such as energy efficiency class, to consumers upfront. Consumers can then access the full label and/or product information sheets with more details by clicking into the display.

Limitations of Existing Infrastructure

In addition to human capacity, online labeling regulations necessitate digital infrastructure which may require investments from online platforms and enforcement agencies. Depending on how websites and webpages are structured, as well as the extent to which the web design is customizable, platform owners often have to work with web developers to build the digital infrastructure for compliant energy label display. Regulations must define a standardized method of displaying labels, both to facilitate compliance for online platforms and to facilitate market surveillance activities.

A web crawler[131] can be a useful tool to assist enforcement agencies in identifying non-compliant webpages; however, this tool is only effective if labels are displayed in a consistent manner so that inconsistencies the web crawler flags are likely indicative of non-compliance, not just variations across webpages. MSAs under the Nordic Council of Ministers developed "NordCrawl" to support their efforts in monitoring online markets of interest. Advantages of the tool include reduced data collection and overall market surveillance costs, higher coverage and better market representativeness, and improved sampling, among others [7]. A study conducted by the International Energy Agency found the web crawler technology to be useful for market insights and policy analysis in addition to compliance assessment, including indications of adaptation rates and patterns in response to policy changes [8]. However, web crawlers introduce concerns around privacy and data ownership that governments must consider.

Market surveillance can also be challenging without a product registration system to compare advertised versus registered product information and verify label accuracy. Compared to product testing and even in-store label inspections, online market monitoring is a relatively affordable market surveillance activity.

[128] "Market surveillance" includes monitoring and verifying compliance with energy efficiency standards and label policy program requirements once products are in the market. This can include inspections as well as verification testing.
[129] "Conformity assessment" refers to demonstration that specified requirements relating to a product, process, or system are fulfilled. This includes testing, certifying, and registering products. Typically refers to assessment of products before and as they are placed on the market.
[130] Nested display refers to a visual interface where an image or data set can be accessed by a mouse click, mouse roll-over, or tactile screen expansion of another image or data set.
[131] A web crawler is a computer program that automatically and systematically searches the content of webpages to collect data.

Countries with Online Labeling Regulation and Enforcement Mechanisms

Although still relatively new, the EU and UK, the US, China, and South Africa have mandatory online labeling requirements.[132] Each of these economies has been selected due to their large or fast-growing online appliance markets.[133] The EU's online labeling regulations and practices are detailed in the case study following this section. Additionally, Australia and Ghana have voluntary online labeling initiatives and have expressed interest in transitioning these into mandatory requirements. Table 2 summarizes the guidelines and regulations currently in place.

United States

The US has a mandatory label for energy-using products called EnergyGuide and a separate label for lighting called Lighting Facts[134] under the Federal Trade Commission (FTC) Energy Labeling Rule [9].[135] The regulation was amended in 2011 and 2014[136] to mandate that manufacturers make labels available on a publicly accessible website—via hyperlink or download—for any product required to bear an EnergyGuide or Lighting Facts label. It also requires all websites advertising regulated products to display a label, for each model, which may be an icon that hyperlinks to the full image so long as consumers can view the image without needing to download any files.

China

In 2016, the National Development and Reform Commission (NDRC) and the former General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ)[137] revised "The Energy Efficiency Label Management Measures" to include a mandatory requirement that the China Energy Label (CEL) be conspicuously displayed on the product information page where a labeled product is marketed online to be sold in China. The requirement does not specify how the label should be displayed; however, the government is engaging with online platforms to explore more specific requirements.

In 2020, a market survey performed by China Market Monitoring identified both existing infrastructure and willingness to leverage this capacity to expand online energy efficiency labeling nationally [10]. Four platforms dominate the online appliance market in China: Jingdong (JD), TMall, Pinduoduo, and Suning. JD and TMall alone accounted for more than 80% of China's online appliance market in 2020. Three of the four online platforms surveyed noted they already had teams tasked with reviewing energy information and labels on appliance listings who could, in the future, assume responsibility for monitoring compliance if provided proper guidance, support, and resources. As a result of this research, CLASP recommended that the energy label management system provide public services for online platforms in energy efficiency information verification and validation.

China National Institute of Standardization (CNIS), the research institute responsible for developing standards and resources for policy implementation as well as operating the China Energy Label management center, adopted CLASP's recommendation in early 2022. CNIS launched an online appliance labeling pilot with e-commerce tycoon Alibaba Group, which reaches over 890 million active users through their online platforms Tmall and Taobao. The pilot grants these platforms open data access to CNIS' China Energy Label management system through a portal where platforms must verify energy labels and energy efficiency information before sellers can list their products for sale online. Authorized platforms can now pre-check labeling compliance before products enter the online market. This infrastructure can also be expanded to allow platforms to calculate and display additional information such as energy saving and emissions reduction potential. The lessons learned from this pilot will be instrumental in advancing online labeling compliance internationally.

[132] This list is not exhaustive. While there are other countries that have mandatory online requirements, we selected these countries as examples to discuss online labeling regulations and compliance enforcement.

[133] There are no current online appliance sales data for Ghana but there are draft regulations with online labeling requirements.

[134] Unlike other labels discussed, Lighting Facts does not rank products on a scale like a traditional comparative label. Only performance and energy cost information are presented.

[135] 16 CFR Part 305 § 305.9 Duty to provide labels on websites.

[136] The requirement was added for televisions in 2011 and expanded in 2014 to all products covered by the Energy Labeling Rule.

[137] The relevant responsibilities of the former AQSIQ now fall under the State Administration for Market Regulation (SAMR).

South Africa

South Africa establishes its labeling rules under the South African National Standard for Energy Efficiency of Electrical and Electronic Apparatus (SANS 941:2020). Separate standards define the product specific rules and the 2017 "Guide for Energy Efficiency Labelling"[138] presents the labeling rules in more detail. The Guide mentions that in the case of distance selling where consumers cannot see the product displayed, sellers are responsible for ensuring consumers are provided with product energy efficiency class and energy consumption data before purchase. Sellers must also indicate the energy efficiency class of appliances on any advertisements or promotional materials for specific models of appliances. While this can be interpreted as applying to online labeling, the rules do not explicitly call out online distance and there is no specific guidance for online retailers. South African policymakers are currently revising the Guide to provide clearer instruction on how to interpret SANS 941:2020. The expectation is that in the longer term, a revision of the standard will more precisely define the obligations for online sales.

Australia

The voluntary Energy Rating label was developed under the Equipment Energy Efficiency (E3) program—a joint initiative of the Australian Government, states and territories and the New Zealand[139] Government. The Energy Rating website offers resources for retailers interested in the voluntary online label display for products regulated under the Greenhouse and Energy Minimum Standards (GEMS) Act 2012 [11]. The recommendations include displaying a simplified version of the Energy Rating Label—the Energy Label Icon—on or near the product image or product description. The icon can be generated using an Application Programming Interface (API) and data extracts from data.gov.au[140] or by downloading a .png file of the corresponding Energy Rating Icon. Retailers are encouraged to use pre-generated CSS code to add the kilowatt-hour consumption figure to the Energy Rating Icon template provided.

The Australian government is interested in exploring opportunities for improving the voluntary scheme before developing a mandatory requirement, which can be a lengthy process for governments in part due to the need for a resource-intensive regulatory impact analysis. To maximize the utility of the Energy Rating Label and Icon, the government is prioritizing behavioral research into how consumers make purchasing decisions and what information influences these decisions. Currently, products sold online which are regulated under the GEMS Act 2012 are only monitored to determine whether they are compliant with mandatory registration in the GEMS Regulator Energy Rating Registration Database. Enforcement can be supported through voluntary cooperation with online platforms.

Ghana

There are no current requirements for displaying the Ghana Energy Guide label for products sold online. Only three products are regulated under the Energy Efficiency Standards and Labelling Regulations; however, the Energy Commission has submitted draft legislation for 17 new product regulations, which is expected to be adopted in the second quarter of 2022. The draft legislation includes a section on obligations for regulated products displayed or sold online, as well as a revision of the Energy Guide label to include QR codes. The intention is to have online platforms indicate a product's efficiency using nested display near the advertised price, which consumers can click to see full label information. Once the regulation is adopted, there will be a one-year transition period for products already on the market to comply with the new requirements while product models entering the market will be expected to comply immediately. Platform owners that need to work with web developers to establish the nested display feature will be encouraged to upload label images on product pages as an intermediary step to full compliance.

The Ghanaian government is prioritizing stakeholder communication and engagement as they work to strengthen implementation of energy labeling regulations and trust in products entering the market. The Energy Commission offers a Certified Appliances mobile app where consumers can search by model number to verify if a product is registered and if the information on the label matches information in the product

[138] https://www.savingenergy.org.za/wp-content/uploads/2017/11/A-guide-to-energy-efficiency-labelling.pdf

[139] New Zealand mirrors Australia's energy labeling regulation. There are separate enforcement authorities, however, online label display is currently voluntary.

[140] The central source of Australian open government data.

database. Consumers can report non-compliant products using the app, which is intended to empower them to become part of the process of strengthening the credibility of the label and trust in regulated products on the market. Once the Energy Guide labels include QR codes, they will be linked to entries accessible within the Certified Appliances app. The generation of unique QR codes is also intended to protect importers by adding an extra level of security since labels cannot be fabricated as easily. The Energy Commission will only generate QR codes when a manufacturer's application to import the product is approved.

Table 2. Countries with Online Labeling Regulations and Guidelines

Economy	Label	Online Labeling Regulations, Agencies, and Authorities
United States	EnergyGuide and Lighting Facts	• Mandatory under Federal Trade Commission (FTC) 16 Code of Federal Regulations (CFR) Part 305: Energy Labeling Rule • Effective 2019, revised 2021 • Enforced by FTC
European Union	EU Energy Label	• Mandatory under European Commission regulation (EU) 518/2014 with regard to labeling of energy-related products on the internet, 2017/1369 energy labelling framework regulation, and product specific regulations • Effective 2015, last revised 2017 • Enforced by individual EU member state authorities
China	China Energy Label (CEL)	• Mandatory under National Development and Reform Commission (NDRC) and State Administration for Market Regulation (SAMR) *Energy Efficiency Label Management Measures* • Effective 2016 • Enforced by China National Institute of Standardization (CNIS)
South Africa	South African Energy Efficiency Label	• Mandatory under South African National Standard (SANS) 941 • Effective 2016, last revised 2020 • Enforced by National Regulator for Compulsory Specifications (NRCS)
Australia	Energy Rating Label	• Voluntary guidelines provided by Equipment Energy Efficiency (E3) program

Case Study: Learning from Energy Labeling Compliance in the EU

E-commerce is steadily growing in the EU, with tens to hundreds of thousands of websites selling energy-consuming products across EU member states. The EU has proactively pioneered the regulation and enforcement of online labeling requirements since 2015. The requirements were revised in 2017 to account for market developments and to improve compliance. The new rules entered into force for the first set of product types in 2021.

Several initiatives investigated online labeling practices[141] and provided insights into the status of labeling compliance, challenges, and lessons learned. The 2020 Special Report of the European Court of Auditors [12] noted that 57% of the inspected products sold online were labeled improperly or not at all. The following sections summarize the EU regulatory environment and findings from detailed research conducted by CLASP in 2020 and published in the paper "Study to Evaluate Online Energy Labeling Compliance in the EU." The

[141] Examples of initiatives: http://www.compliantv.eu/eu/energy-label-display/online-survey, http://www.come-on-labels.eu/displaying-energy-labels/appliance-labelling-in-shops, https://eepliant.eu/index.php/new-products/wp4-refrigerating-appliances/61-new-products/new-eepliant-2-wp4-5-6/63-wp4-household-refrigerating-appliances-2

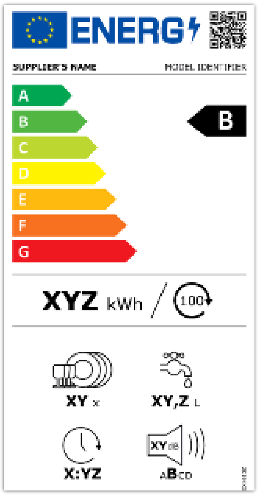
study assessed how accurately online platforms across the EU displayed energy labels and provided other required product information during the transition to the new labeling requirements. The aim of the study was to investigate cases of non-compliance and make recommendations for addressing these mounting concerns and improving compliance rates.

EU Regulatory Environment: Energy Label Legislation Overview

The EU started union-wide categorical labeling of product energy performance in 1992. The program now covers 15 product groups and is considered a success story in achieving energy savings and greenhouse gas emission reductions as well as in earning consumer trust. The positive outcomes of the program have led to its replication in other regions [13]. A 2019 study found that nearly 80% of EU consumers understand the energy label and use it to inform their appliance purchases [14].

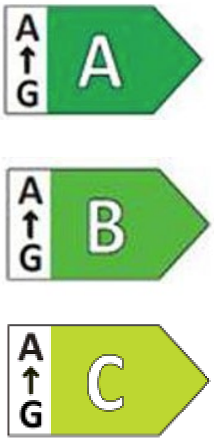
Regulation (EU) 2017/1369 [15] sets the framework for energy labeling in the EU while the details (e.g., content and design, stakeholder responsibilities for individual product categories) are defined in product-specific regulations. The energy label is designed to be language neutral to make the information accessible throughout the EU, including visual representation of product performance information through pictograms. The information displayed varies depending on the product group. The energy label is in the process of being rescaled for individual product categories by ranking energy efficiency on a scale from A (highest efficiency, with a green arrow) to G (lowest efficiency, with a red arrow) (Figure 5). The new rescaled label was introduced in March 2021 and currently applies to refrigerators, dishwashers, washing machines, audio-visual displays (e.g., television sets, external monitors), and light sources. New labels are expected to be adopted for other products in the coming years. Until then, labeling regulations for some products still fall under Directive 2010/30/EU, complemented by Regulation (EU) No 518/2014 for the online market.

Figure 5. Sample Rescaled EU Energy Label



Source: European Commission[142]

Figure 6. Sample Efficiency Class Arrows to access the label from a nested display



Source: European Commission[143]

[142] https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/dishwashers_en

[143] https://energy.ec.europa.eu/topics/energy-efficiency/energy-label-and-ecodesign/energy-label-templates_en

EU Online Labeling Requirements

Prior to 2015, the EU had requirements for displaying labeling information in distance selling channels such as printed catalogs but did not have targeted energy labeling rules for online sales. Systematic rules for displaying energy labels online have only been in force since 2015, under Regulation (EU) 518/2014 [16]. While the new rules for online labeling are now defined in Regulation (EU) 2017/1369, the CLASP study took place when the previous framework still applied for all products. In this case study we refer to the rules that were in force at the time of the study; however, the rules for online labeling vary only slightly and therefore the recommendations still apply.

One of the key obligations in (EU) 518/2014 is displaying the energy label in proximity to the price of the product. Consumers should not be forced to scroll or open another webpage on any device, including tablets and mobile phones, to see the energy label information. Alternatively, an online platform can use a nested display image indicating the color-coded energy class of the respective product model (see the arrows in Figure 6). The size of the energy class letter must be at least the same font size as the price. Sellers are also required to provide a link to the product information sheet,[144] which can be stored on the website or linked directly to the EPREL database. Figure 7 shows a sample proper display of online energy label, using a nested display arrow with a link to the full energy label and a link to the product information sheet.

Figure 7. Sample Proper Display of Online Energy Label Using Nested Display Arrow

Source: Adapted from Irish Market Surveillance Authority's guide[145]

Annex X of the (EU) 518/2014 regulation stipulates that online labeling requirements apply to all online retail sites making an offer for *"sale, hire or hire-purchase through the internet"* of regulated products directly to consumers. If the consumer can locate the model price on the webpage and are able to order a product from the webpage—either directly or by email or phone—then such webpage is subject to online labeling requirements. The energy label and the link to the product information sheet must be displayed on every webpage within the website that links product to sale (e.g., product-specific page, comparison page, shopping cart).

Table 3 provides an overview of key market actors engaged in regulated product sales. If a manufacturer sells a product directly to consumer, they become a seller and are required to fulfil the corresponding obligations. Similarly, a retailer importing a product that is sold under their own brand is held accountable to the supplier's obligations.

[144] A "product information sheet," previously known as a "fiche," is a document containing a specific set of information relating to the respective product as defined under product specific regulations.

[145] https://www.seai.ie/publications/A-Retailers-Guide-to-Online-Energy-Labelling.pdf

Table 3. Key Supplier and Seller Obligations for Displaying Online Energy Labels in the EU

Supplier Obligations	Seller Obligations
• Prepare energy label & product information sheet • Supply an electronic label & product information sheet, and, if required, register product in EPREL • Refer to the efficiency class & range of classes available on the label in visual advertisements or technical promotional materials	• Display energy label & product information sheet • Refer to the efficiency class & range of classes available on the label in visual advertisements or technical promotional materials

Source: CLASP Study to Evaluate Online Energy Labeling Compliance in the EU

As of March 2021, online retailers are required to display the new energy label (Figure 5) for refrigerators, dishwashers, washing machines, and television sets (including other external monitors). New labels apply to light sources as of September 2021 and legislation will be introduced for other product categories in the future. Together with the revised label, the EU revised requirements relevant to online label display include: 1) product fiche is now referred to as product information sheet, 2) online retailers that sell EPREL-registered products can provide a link to the product information sheet in the EPREL database rather than making it available for download directly from the website, 3) marketplace owners are required to set up digital infrastructure for third-party sellers to display energy labels and product information sheets provided by suppliers, as well as inform the seller of their obligation to display them.

Study Methodology

In late 2020, CLASP conducted a study to assess the proper display of energy labeling information on websites based out of six EU member states [13]. The study analyzed the display of labeling information for over 3,000 product model pages on 72 online retailers and other websites in Belgium, the Czech Republic, Denmark, Germany, France, and Slovakia. The study investigated online retailers, specialized sellers, low price segment e-shops, do-it-yourself,[146] and high-end sellers, as well as price comparison websites. The investigation covered product-specific webpages, online platform main webpages, product group webpages[147], shopping cart (basket), comparison webpages, as well as online retail site advertising and leaflets. The study assessed proper availability, location, and size of the mandatory energy labeling information.[148]

The team also conducted surveys, webinars, and consultations with stakeholders including supplier associations, market surveillance authorities, retailers, and retailer associations about their perspectives on the clarity of the legislation and main sources of non-compliance. The study established a typology of non-compliance cases (availability, readability, accuracy, and additional mentions[149]) and provided a quantitative and qualitative assessment of the level of compliance observed during the study to inform recommendations for improving online labeling compliance in the EU. While framed in the context of the EU, the lessons learned from this study are transferrable to other economies.

Study Findings

Overall, while most online platforms made some effort to display energy labels, almost all of the platforms assessed in the study had some compliance issues. On average, the observed level of compliance to EU online labeling rules was relatively low. Many suppliers and sellers had procedures in place to effectively exchange information and ensure compliance; however, the study identified some market segments, such as marketplaces, that require targeted improvements due to high levels of non-compliance.

[146] "Do-it-yourself" sellers usually sell goods and tools for home renovation and decoration, but also occasionally sell major appliances and light sources.

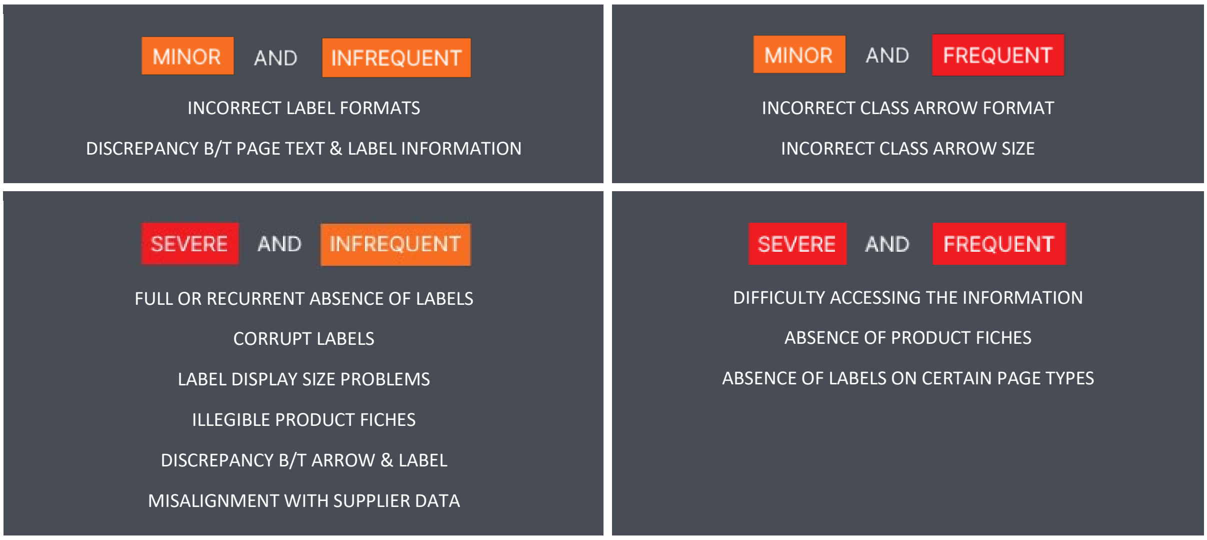
[147] "Product group webpages" refer to product category pages or catalogs where several models are shown next to each other.

[148] The study took place in late 2020 before the adoption of new energy labels and related requirements (in March 2021 and September 2021) for the selected product categories. Some details have changed between the two legislations (e.g., the graphic design of the arrow) but most requirements remained the same.

[149] "Additional mentions" are statements found on websites that may not be covered by energy labeling regulations per se but can also influence consumers, and in some cases, offer misleading information that hinders the effectiveness of energy labeling.

As shown in Figure 8, the most frequent non-compliance issues were related to difficulty accessing the energy label information. This includes energy labels or nested displays not being placed in the proximity of the price, incorrect graphic formats or sizes, absence of the mandatory product information sheets, and absence of labels on some page types (i.e., catalog, shopping cart, and comparison pages).

Figure 8. Types and Frequency of Non-Compliance



Source: CLASP, Study to Evaluate Online Energy Labeling Compliance in the EU

Since most websites were found to show conformity issues with the online labeling rules, the overall compliance score was orange based on the compliance scale[150] used in the study. “Difficulty accessing the information” was among the most frequent and severe case of non-compliance. This included cases when the energy label was not located “in the proximity to the price” but for example in the picture gallery[151] or in a product description at the bottom of a page. Furthermore, missing product information sheets was a very common case of non-compliance, as well as the absence of energy labels on all online retailer pages other than the product page. Other non-compliance cases identified were less frequent or less severe, e.g., modified energy labels, unreadable product information sheets, or incorrect size of the energy class arrows.

[150] The scoring system ranked retailers on a scale from green to red, ranging from 1) perfect or nearly perfect compliance for both the energy label and product information sheet, meaning that although labels were available for nearly all available models in a correct format, they may not have been very close to the price but were still easy to find; to 2) only approximate and non-systematic compliance; to 3) systemic non-compliance where labels were fully or largely missing or hardly accessible.

[151] “Picture gallery” refers to a set of pictures that display individual product model designs. Sometime energy labels are included among such pictures, but the consumer must open the picture gallery to access the information.

Figure 8. Compliance by Online Platform Category

Source: CLASP, Study to Evaluate Online Energy Labeling Compliance in the EU

Figure 8 shows that the do-it-yourself segment performed the best out of investigated categories, which may be explained by the fact that they offer fewer appliances, simplifying maintenance of the content. The study did not observe significant compliance differences between the remaining types of shops investigated (large online platforms, low-price, and specialized online retail sites). The evaluation of **price-comparison** websites—which have no direct legal duty but are highly relevant to consumers—also showed a very low level of compliance with energy labeling requirements as shown in Figure 8.

Among investigated online platforms (excluding price comparison websites), 23% showed very poor compliance with displaying energy labels (e.g., having no labels or labels frequently missing) and 58% displayed no or very few product information sheets. Only four online retail websites fully complied with rules for all the investigated product groups, representing 5% of study sample. Only around 27% of all investigated websites demonstrated minimal or no non-compliance.

During the interviews, retailers identified challenges that prevented full compliance—even despite efforts to comply—such as lack of clarity of requirements, complexity of requirements, and lack of alignment of guidance across EU member states. Retailers operating in several economies may receive mixed information on properly implementing labels and MSAs in different countries may interpret the requirements differently. The study's findings emphasized that clear guidance with simple and precise requirements for retailers and regular communication with them and their associations would be one of the most efficient means of improving online labeling compliance.

Recommendations for Online Labeling Compliance

The EU online labeling compliance study provides insight into key challenges to and opportunities for regulating and enforcing online labeling that can benefit economies interested in implementing or strengthening online energy labeling regulations, as well as related compliance and enforcement mechanisms. These insights are supplemented by lessons learned from other economies proactively exploring online labeling requirements.

Early Engagement of Online Retailers

Pilot voluntary requirements with online platforms. While a mandatory online labeling requirement is the ultimate—and time sensitive—end goal to maximize compliance and ensure consumers have access to the same information regardless of where they make purchases, this may not be immediately feasible. Governments may face requirements to first perform a regulatory impact analysis and build an understanding of the online market landscape for regulated products, potentially including market assessments. These are useful tools to optimize regulations, however, they can be resource-intensive and time-consuming processes that should not forestall exploration of online labeling opportunities. Governments can immediately identify potential partners and initiate pilot programs to test out online labeling requirements implemented by online platforms, which can exercise flexibility in adjusting their policies on a voluntary basis.

These pilot programs can provide key insights into potential challenges online platforms may face in adapting to requirements and potential solutions for overcoming these barriers. Voluntary requirements risk low participation rates and minimal impacts to the broader online market, but strategic partnerships can help secure stakeholder buy-in for a transition to mandatory online labeling. This voluntary phase can also be combined with consumer behavior research to identify what requirements would have the most impact on consumer purchasing (e.g., what label information helps consumers make purchasing decisions and should therefore be prioritized for online display requirements).

Regulatory Considerations

Introduce mandatory online labeling requirements. We recommend introducing a mandatory requirement to display labels on online platforms to ensure consumers receive the same information regardless of where they make purchases. The timelines in which platforms will need to adapt the new requirements will vary depending on the number of online platforms in the economy as well as their existing digital infrastructure and human capacity.

Ensure regulations are easy to understand and clearly outline roles and responsibilities. Unclear requirements can result in lack of commitment from online retailers and high levels of non-compliance, potentially reducing consumer trust in energy labels. All requirements must be easily understandable for potentially thousands of online retailers and platforms, including explicit guidance on label size and location as well as screen formats for different types of pages, browsers, and devices (e.g., computers, tablets, mobile phones). However, it is important to outline the requirements for all specific situations by providing succinct rules that are easy to interpret and comply with, avoiding grey areas or loopholes. The roles and responsibilities of different parties should be well defined, including in cases of international sales and marketplaces. One option to navigate the complexity of international online markets is to require sellers to have a locally registered branch or legal representative. The EU framework regulation for online labeling can be referenced as a starting point considering the improvement opportunities identified in CLASP's "Study to Evaluate Online Energy Labeling Compliance in the EU."

Technical Solutions for Compliance and Enforcement

Automated tools can help systematize online labeling compliance. Online retailers may need technical assistance to comply with online labeling requirements. Label generation should be the responsibility of regulatory agencies or suppliers to maximize efficiency and prevent the circulation of conflicting labels for the same product model. Providing ready-to-embed modules programmed to display all the necessary information in the required format can facilitate higher compliance rates. A product registration system is an advantageous resource for facilitating this process, allowing registered product information to be easily extracted and linked to the module that embeds labels for online display. In the absence of an integrated product registration system, regulators can request the suppliers provide high quality digital label images to the retailers for manual upload.

Automated tools can also facilitate online labeling market surveillance and enforcement. Governments should ensure market surveillance authorities have the infrastructure and human capacity needed to regularly monitor and enforce online labeling compliance. If label display is standardized, authorities can use web crawlers to streamline monitoring online labeling compliance, as well as for market insights and policy analysis. Initial verification activities can identify market segments with the highest levels of non-compliance (per product, retail categories, or other criteria), which can help design targeted product verification strategies. A product registration system can also facilitate the verification of advertised versus registered product information.

Awareness and Guidance

Prioritize communication with stakeholders. To comply with regulatory requirements, each part of the supply chain needs to have a clear understanding of the regulations. Governments should invest in raising awareness about new regulations and clearly communicate to each type of online platform and seller what the new requirements are, how to comply with their respective legal duties, the consequences of non-compliance, and how the requirements benefit both sellers and consumers. Personalized evaluation, recommendation, and follow-up can help ensure the recommendations were well understood and properly implemented. These efforts can include trainings and guidelines documents, as well as increasing the visibility of surveillance and enforcement activities to deter non-compliance. Engaging business associations and suppliers who play a key role in distributing labels to sellers can help amplify awareness and strengthen buy-in from online retailers and platforms. Governments should also provide consumers with resources to understand energy labels and encourage them to look for and reference the labels when making online purchases.

Improving Online Retailer Internal Procedures

Internal monitoring of labeling compliance. Governments and retailers' associations can improve compliance rates by providing online retailers with guidance for improving their internal procedures. Helpful guidance may include how to raise awareness about the requirements across internal departments to enhance consistent compliance with regulations, which is particularly important in the case of third-party sellers and marketplaces. Online retailers should also develop strategies for systematically monitoring compliance and proactively responding to instances of non-compliance internally, prior to enforcement authorities flagging them.

Conclusion

As online markets continue to grow rapidly, it is becoming increasingly urgent for governments to adopt and improve online labeling regulations. Online labels ensure consumers have access to the same information whether purchasing regulated products in brick-and-mortar stores or online. This consistency in label display is necessary to secure market transformation, emissions reduction, and energy conservation targets, as well as consumer trust in energy efficiency programs.

Since this is a relatively new and developing field within energy efficiency policy, few countries currently have such programs and regulations in place. This gap in policy offers opportunity for international leadership in developing and sharing best practices, such as those emerging from current online labeling regulation pioneers (the EU), early adopters (the US, China, South Africa), and economies assessing possibilities (Australia, Ghana). The EU online labeling compliance study provides insights and lessons learned for economies interested in developing or strengthening online labeling compliance regulations.

Governments should launch pilot programs with online platforms and implement mandatory requirements as soon as feasible to establish effective strategies for regulating online labeling. Considering the online market is more complex compared to brick-and-mortar shops, regulations need to clearly define which websites and webpages will be regulated and the roles and responsibilities of online retailers and enforcement authorities. Governments then need to raise awareness about requirements and provide guidance on internal processes that online retailers can leverage to improve compliance. Investing in communication with platform owners can help increase compliance and offset monitoring demands on enforcement authorities, as well as help governments better understand the impact requirements have on platforms. Insight into consumer behavior can help governments formulate how to make requirements useful to consumers without imposing unnecessary burdens on online retailers. Investments in tools such as product registries and web crawlers can further systematize market surveillance and enforcement activities, as well as provide benefits beyond online labeling.

Online markets will only grow in the coming years, granting governments a limited window to begin proactively investing in infrastructure to support online labeling compliance and enforcement. There is great opportunity for governments to join—or rise among—the other early leaders in the developing field of online labeling and contribute to the knowledge exchanges that will give rise to the establishment of much-needed international best practices.

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Efficient Coffee Machines – European energy label for residential and commercial use

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Keywords:

- Success story of the Swiss Energy Label for residential coffee machines
- Adaptation for a European Energy Label
- Learnings for an Energy Label for commercial coffee machines
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Abstract

Since 2015, Switzerland has a mandatory energy label for residential coffee makers (based on the measurement standard EN 60661:2014 and Regulation (EC) No 1275/2008 on standby). While the adoption of auto-power-off and low standby was driven by the EC standby regulation, the Swiss label led to the adoption of more efficient technologies (e.g., boiler insulation, flow through-type heaters). The annual consumption of coffee makers dropped from an average of 180 kWh (2006) to below 50 kWh for efficient models (2018). This success could be transposed to the EU, regulating a much bigger market, and thus saving much more energy.

A recent study for the Swiss Office of Energy (Bush et al, 2021) investigates energy efficiency of commercial coffee makers. While some differences exist for residential and commercial coffee makers, there are also many similarities. The higher complexity of commercial coffee makers poses a challenge for developing a comprehensive testing standard (measuring the production of several different kinds of beverages with high accuracy). CENELEC is currently working on such a testing standard (CLC/TC 59X/WG 21). Other approaches focus only on energy losses as one of the key drivers of efficiency considering that the main energy for production of coffee is heating up water.

This paper discusses the success of the Swiss energy label for residential coffee makers and its possible application to the European market as well as for commercial coffee makers. The trade-off between a pragmatic measurement method and the complexity of commercial coffee makers is discussed.

Introduction

Topten, the author of this paper, is an independent platform that presents the most energy efficient products on the market for household and commercial use. To be listed, products need to fulfill the selection criteria defined by Topten. They are based on existing standards and regulations and consider the product's energy efficiency and environmental impact, resource efficiency and health impacts. The platform is used by policymakers as a source of data and science-based recommendations to develop new regulation.

This paper first looks at the success story of the Swiss energy label for residential coffee makers. The development that led to the introduction of the energy label was a complex process from studies showing the impact of coffee makers as well as proving the feasibility of test standards. The exchange and group effort together with manufacturers and regulators eventually led to the improved, yet simple testing standard that is widely accepted as a basis for defining energy efficiency classes for the label. The at first voluntary label from 2009 was adapted to the new standard and made mandatory for Switzerland in 2015. Because many manufacturers already measure their models for the Swiss market, an introduction of the same label for the European Union is easily feasible and the only logical conclusion. The most efficient models are presented on Topten Switzerland www.topten.ch/kaffeemaschinen.

For commercial coffee makers this paper is evaluating the differences, but also similarities in comparison to residential coffee makers, which could lead to the adaptation of the existing energy label also for the commercial use. Topten is already presenting a list of energy-efficient models on www.topten.eu/commercial-coffee-makers. The existing test standards EN60661:2014 (testing norm for the residential coffee makers) and DIN 18773-2:2016 (testing norm for commercial coffee makers, focussing on energy losses alone) are evaluated, their strengths and weaknesses highlighted.

Residential coffee makers

Types of coffee makers for residential use

Most common types of coffee makers in Switzerland are fully automatic, portioning machines and portafilter espresso machines. These machines all produce coffee per cup (or sometimes 2 cups at the same time). Depending on the country, drip filter coffee machines are also very popular. Here, a larger amount of coffee is produced and stored in a pot (insulated or not), which is kept warm directly in the machine.

Other ways of producing coffee at home which require electricity to boil the water in a kettle or on the stove are the stove-top espresso makers, manual drip/filter, french press, brewing coffee directly in a pot, etc. Cold brew coffee doesn't even require boiling water.

We focus here on the electrical appliances and their energy use.

Table 1. Typologies of Residential Coffee Makers

Fully automatic	**Portioning machine**	**Portafilter espresso machine**	**Drip filter coffee machine**
 Jura	 Nespresso	 Sage	 Breville

For the following considerations, drip filter coffee machines are not considered, because they are not common in Switzerland. Therefore, they don't require the Swiss energy label. However, in the European market, drip filter coffee machines do have a substantial market share. How big that share is, differs from country to country, but can be up to 40%. There are models with integrated grinders as well, but essentially the technology can be compared to electric water kettles, there is no pressure element. The issue concerning energy consumption with drip filter coffee machines is the keep-warm function for the brewed coffee. This can be up to 100 W, sometimes over 10h per day. There are models with insulated containers to lower this energy consumption, but by far not all models have this feature.
The measuring standard used for the Swiss energy label (EN60661:2014 [3]) is also applicable for drip filter coffee machines, thus all the following statements are still valid.

Some models can also be used in a commercial setting, mostly for smaller offices, small shops, medical practices, etc. Usually, the differences occur in the daily output of cups as well as maintenance and cleaning. The risks of using machines designed for a household use in a commercial setting are that the lifetime of the machine is reduced (replacement of parts, higher maintenance, etc.)

The history of the Swiss energy label for residential coffee makers

Switzerland has, as opposed to the much bigger market of the European Union, a mandatory energy label for residential coffee makers. How did it come to this?

In 2006, Topten and S.A.F.E. proposed the introduction of an energy label for coffee makers in a contribution at EEDAL conference [12]. In 2009, the voluntary energy label for residential coffee makers, very similar in nature to the energy label already common for other residential products, was approved [8]. However, it did not work as anticipated, as only coffee makers in the efficiency classes A and B were labelled. Less efficient coffee makers were not declared with the energy label. Thus, the goal of providing consumers with better information on energy-efficiency was not sufficiently achieved.

Shortly after the introduction of the label, in 2010, Topten could provide input for the CECED (now Applia, European Association of home appliance manufacturers)-Working Group TC59X-WG15 with new insights on their testing method. It became obvious that the norm discussed was not yet the optimal testing standard for the energy label. The work on a new measuring standard began, which eventually concluded with the integration in EN60661:2014 [3].

In accordance with SFOE (Swiss Federal Office of Energy), FEA (Swiss Association of Manufacturers of Electric Appliances for residential and commercial use) began working on further developing the existing energy label for residential coffee maker in 2012. After many meetings, phone conferences and written correspondence, a consensus was found where all members of CECED agreed on the subsequent procedure, which was presented to SFOE mid 2014. CECED agreed to conduct round robin tests, which FEA then was able to present, concluding in a Letter of Intent. In there were also the main points described for the adaptation of the energy label for residential coffee makers, such as the scaling from A+++ to D. The work was concluded mid 2015, just in time for the revision of the EnEV (Swiss Energy Directive) [4].

At the same time, Electrosuisse (Swiss Association for Electrical Technology, Energy and Information Technology) conducted a comparison of the two measuring methods, the existing one used for the voluntary energy label and the new method, developed by FEA [14]. Consequently, in 2015, the energy label for residential coffee makers became mandatory, using the newly developed FEA measuring method.

In 2016, Topten conducted a study with comparing measurements using the FEA-measuring norm and EN 60661 [2]. This was the basis on which the energy label for residential coffee makers was revised as of August 1st 2016, resulting in a new look, a new classification as well as based on the international measuring standard EN60661:2014 [14]. In addition, also the ErP (Commission Regulation (EU) No 1275/2008 [6] and Commission Regulation (EU) No 801/2013 [7]) was adopted, meaning all coffee makers have to have an auto-shut-off of 30 minutes as factory setting (Commission Regulation (EU) No 801/2013 [7]) that cannot be changed by the user to a longer period.

Possible future considerations of the energy label for residential coffee makers

While the label provides a good basis for the general machine types, there are some shortcomings for portafilter machines, a type of machine which is increasingly popular, especially in the high-end range. Because most of these machines operate with a boiler, it is nearly impossible to reach a higher energy efficiency class. If the consumer is looking for features like a dual-boiler (simultaneous brewing of coffee and steam production for milk-foam), it is almost impossible to find good machines by simply looking at the energy efficiency class.

There are a few models available that use thermal-flow-through technology which significantly lowers the energy consumption. The best models use less than 10% compared to the average model using boiler technology. Yet, they are in the same energy efficiency class.

However, this concerns only a smaller portion of the market for rather high-end products (price range is 1000-3000 Swiss francs), whereas fully automatic machines are priced below 1000 Swiss francs, and portioning machines for up to 200 Swiss francs, many even below 100 Swiss francs. Of course, there are always exceptions with higher prices for extra functions (such as a steam wand or special design), but this is the general price range. The recommendation of Topten is to not include exceptions in the label.

Commercial Coffee Makers

While the path to higher energy-efficiency for residential coffee makers seems very clear, commercial coffee makers only recently came into focus.

European Policy

Preliminary study for Ecodesign Working Plan (WP) 3 (2014)

Findings as presented in [1] showed rather low energy saving potential for commercial coffee makers. The lack of data made it very difficult to estimate realistic savings for the various machine types.

Dropped from Ecodesign WP3 (2016)

In 2016, the European Commission dropped tertiary hot beverage equipment from the Ecodesign Working Plan 3 (2015–2017) [5].

Preliminary study for Ecodesign WP4 (2021)

In February 2021, the draft version of the new preparatory study for the next Working Plan 4 (2020-2024) was released [15]. After reviewing work from Topten ([13], [9]), the saving potential was revised and is now more than double compared to what was presented in the previous preparatory study from 2014 [1].

New testing standard CLC/TC 59X/WG 21 by CENELEC (pending)

CENELEC is currently working on a new standard: CLC/TC 59X/WG 21 "Professional and commercial coffee machines". It is similar to the EN 60661 [3], combining various use phases (heating up, ready, standby, cleaning) as well as the actual production of beverages, incl. the steam function. The standard can be used for all machine types by simply only measuring what is present in the particular model.

Various types of commercial coffee makers

What is considered to be a commercial coffee maker? The scope includes commercial coffee machines of the types fully-automatic and semi-automatic, as well as manually operated machines such as portioning machines and portafilter espresso machines. There are machines with and without the internal use of fresh milk. Machines which use fresh milk have a higher energy consumption because for one, the milk needs to be kept cold. In addition, in order to heat up the milk and create steam, additional technology (steam-boiler, milk pump) is required. Machines without usage of fresh milk sometimes offer a manual steaming option (semi-automatic), they may use powdered milk for mixed coffee beverages, or they only offer pure coffee beverages without any milk. In terms of coffee type, machines are available for instant, ground and bean coffee which means that some have built-in grinders.

A distinction is made between free-standing or tabletop fully-automatic machines, tabletop semi-automatic machines and tabletop portafilter machines. The last two types of machines differ from fully-automatic machines in that they require trained personnel to operate them (manually steaming milk for semi-automatic, or operation of the entire machine for portafilter), whereas fully-automatic machines can be operated independently by the user. Professional portioning machines are also included as a further subgroup. These can also be considered fully- or semi-automatic except for the insertion of the capsule/pad and are therefore not treated separately.

Free-standing hot beverage machines are designated for busy places and include a vending function. In the table-top category there are vending and non-vending machines available. Table-top hot beverage machines are designated for offices and gastronomy; they have an average throughput of 5 to 50 litres/day.

There are also various types of filter machines, but these are hardly used in Switzerland and were therefore not considered in the study conducted by Topten. However, for other countries, they still matter and are therefore included in the preparatory study [15] with their respective saving potentials. Batch and bulk commercial coffee brewers which seem to be more popular in the United States, are not considered. Batch commercial coffee brewers have a brew volume capacity of 24-384 oz. which is about 0.7-11.5 litres. Bulk commercial coffee brewers have a brew volume capacity larger than 11.5 litres.

Some models built for the use at home can also be used in a commercial setting, mostly for smaller offices, small shops, medical practices, etc. Usually, the differences occur in the daily output of cups as well as maintenance and cleaning. The risks of using machines designed for household use in a commercial setting are that the lifetime of the machine is reduced (replacement of parts, higher maintenance, etc.).

Table 2. Typologies of Commercial Coffee Makers (adapted from [9])

Fully automatic: Free standing	Fully automatic: tabletop	Semi-automatic: tabletop	Portafilter espresso machine
			
Coffeetek NEO	Franke FCS4026	Egro Zero + Pure Coffee	La Marzocco Linea Classic
Portioning machine	Filter: Batch brewer	Filter: Satellite Coffee Brewer	Filter: Urn
			
Nespresso Aguila Range	Bloomfield Koffee King 3	Bloomfield Pourover Airpot	West Bend Coffee Urn

Market overview

The stock of commercial coffee makers for 2025 in the EU was estimated at 5.9 Mio units, consuming 13.6 TWh per year. Estimates of annual sales are roughly 700,000 by 2025 [1]. However, these numbers were recently revised and updated in the draft of the new preparatory study for Working Plan 2020-2024 [15].

Table 3. EU-27 Stock and sales estimates (adapted from [15])

Type of coffee maker	2017 stock	2030 stock (forecast)	2030 sales (forecast)
Free standing vending Table-top vending Table-top, non-vending	1,177,904 1,160,482 1,160,482		
Total Vending and table-top	3,498,867	3,052,570	316,055
Portafilter espresso Batch and Bulk brewer	1,278,460 714'434	1,584,327 821,450	131,704 217,311
Total	**5,491,761**	**5,458,347**	**665,070**

Table 4. EU-27 Estimated Energy consumption and GHG emissions 2030 for the use phase (adapted from [15])

Type of coffee maker	Stock	TWh/a Electricity	PJ/a Primary Energy	1000 t/a GHG
Total Vending and table-top	3,052,570	8.6	64.8	2,915
Portafilter espresso	1,584,327	1.6	12.3	555
Batch and Bulk brewer	821,450	2.4	17.8	801
Total	5,458,347	12.3	95.0	4,271

Differences between commercial and residential coffee makers

What makes a commercial coffee maker so different from its residential counterpart that the same testing norms and energy label could not simply be apply as well? Eventually it still produces coffee, can be argued. If you take a closer look, commercial coffee makers do differ in some ways, but are very similar in general.

Higher capacity, speed of production: in most cases, commercial coffee makers need to deliver promptly, there is no time for tedious preheating the machine, while you might be patient enough for it at home. At work, you just push a button and expect your coffee to be filled into the cup immediately after. Similar in a restaurant: the table of eight guests all want their coffee served together, without the first one already being cold because you have to wait for the machine to finish making the other six cups. This is the reason why commercial coffee makers are built to deliver: their capacity to deliver a certain number of cups per hour is often much higher. Many of the high-capacity models are also built to produce several beverages at once (e.g., you can fill two coffee cups while steaming milk and fill a cup with hot water for tea, all simultaneously). To do so, more technology is built in, which consumes more energy than a simpler model.

Higher automation in places with no regular personnel: While your machine at home often greets you with the "empty coffee grounds" or "empty tank", commercial coffee makers are much more automated. The available beverage types, when to start the cleaning cycles, the auto-off function and much more can all be programmed for many models. With automatic residue removal, freshwater supply and large coffee bean hoppers, these machines can be left alone for a long time before it needs to be restocked and maintained.

Trained personnel: most machines require trained personnel at some point. Two cases can be distinguished:

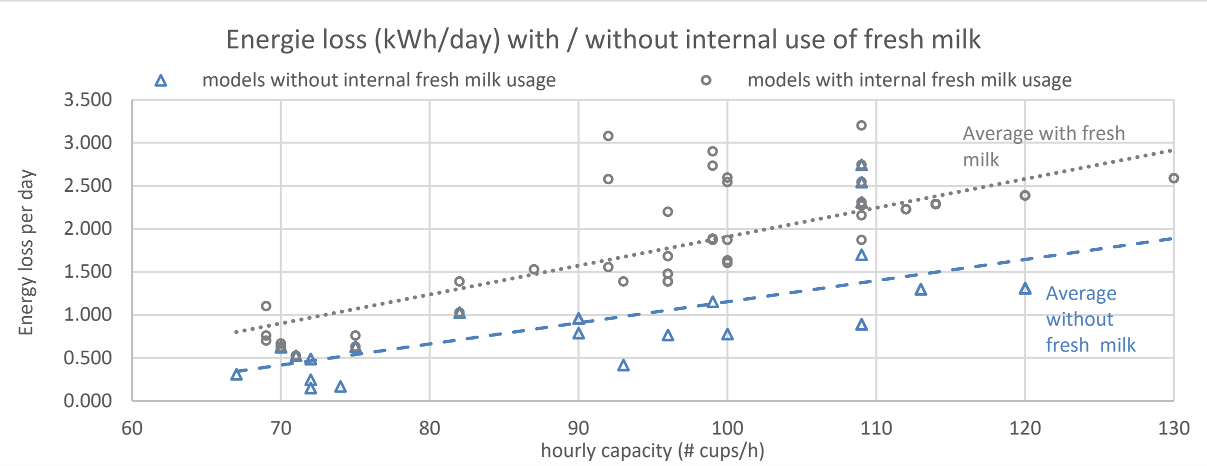
Maintenance and re-stocking: be it merely for refilling (coffee, milk, powders) or regular, deeper cleaning cycles than the automatic ones. This is usually done by initial training by the manufacturer or reseller. For offices, this could be a designated employee responsible for the coffee maker, cleaning staff or canteen personnel. Similar for coffee take-away in places like self-serving restaurants, shops, gas-stations, etc., it is usually an employee taking care of the coffee maker.

Some machine types like portafilter espresso machines can only be operated by highly trained personnel (barista) even for producing the beverages, not only maintenance and restocking. For these type of coffee makers, the art of making coffee is celebrated. Often these machines are also a design showstopper in a bar, café, or restaurant, where the customer can clearly notice and appreciate the effort and work that goes into their beverage.

High variety of products: Fully automatic models often offer various types of coffee beans (decaf, organic, light roast, dark roast), milk-types (normal, lactose free, skim, vegan), flavoured syrups to be added in the beverage, even cold versions of the classics to choose from.

Use of fresh milk: Although this is trending as well for residential coffee makers, a big difference is the usage of fresh milk, which is kept cold directly in or nearby the machine, ready to be heated and frothed. In comparison: most residential coffee machines that use fresh milk do not have a cooling unit, the milk needs to be placed back in the fridge for cooling. However, the external milk cooling of commercial coffee makers uses additional energy in combination with the readiness to produce any beverage right away (mentioned above), additional technology (steam boiler) has to be kept ready to operate immediately. In case of the steam boiler, this means having the pressure and temperature ready to heat and froth the milk. In Figure 1, the differences in energy loss are shown for the models listed on the Topten website. These models are measured according to DIN-18873-2 the energy for cooling the milk itself is not included here, but measured separately, because the machines usually can be combined with various milk refrigerators. This means the actual energy loss associated with a coffee-milk-beverage such as cappuccino is even higher.

Figure 1. Overview on models showing their energy loss, rated by the hourly coffee capacity and grouped by using fresh milk or no fresh milk.



Saving potential of commercial coffee makers

In 2016, the European Commission has abandoned tertiary hot beverage equipment from the Ecodesign Working Plan 3 (2015–2017) [5], as the estimated energy saving potential of 1.2 TWh per year was considered as too low (in 2030 in the EU). Topten conducted a brief plausibility check of the underlying preparatory study and concluded, that this estimated saving potential seemed far too low. According to [13] the actual saving potential for the EU in 2030 lies more around 4 TWh per year, taking into consideration standby and higher saving potential for different types of commercial coffee makers.

As presented in the draft version of the preparatory study for the Working Plan 2020-2024 [15], the saving potential has been revised and is now more than double the amount from the previous study with 2.6 TWh per year by 2030. However, it is still lower than what Topten has proposed due to comparison with an average model instead of the best available.

Table 5. EU-27 Saving potential for Energy consumption and GHG emissions 2030 for the use phase (adapted from ([15], [13])

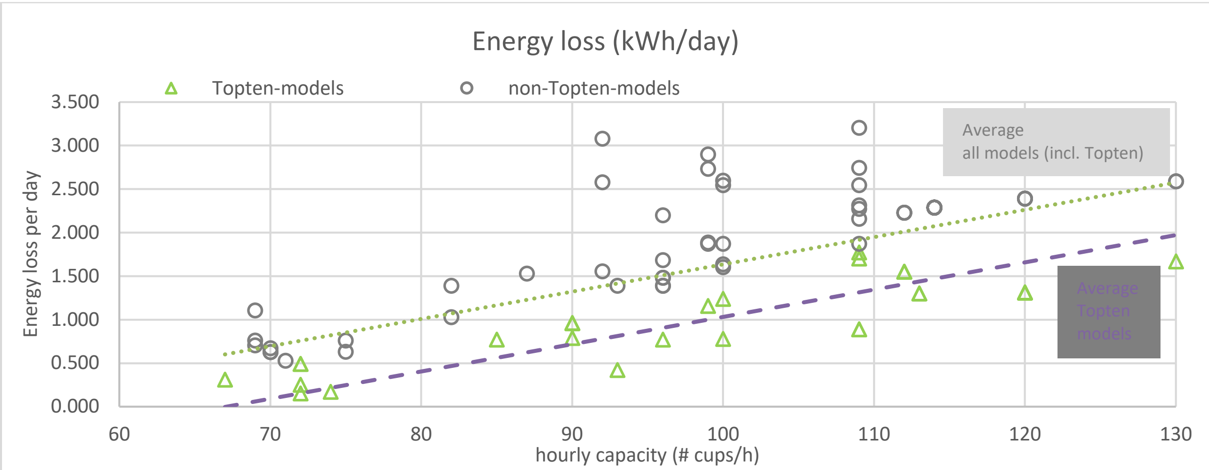
Type of coffee maker	TWh/a Electricity [15]	PJ/a Primary Energy [15]	1,000 t/a GHG [15]	Electricity (TWh/a) Topten [13]
Free standing	0.6	4.3	188	0.7
Tabletop	0.4	3.1	135	0.7
Portafilter espresso	1.5	11.0	538	2.6
Batch and Bulk brewer	0.0	0.2	8	n/a
Total	2.4	869	4,271	4.0

In particular, Topten has been estimating the potential savings for portafilter machines to be even higher than presented in [15]. These machines very often run 24/7 and are never shut down completely. Thus. we deem the saving potential to be higher.

Fully-automatic commercial coffee makers

As of 2020, Topten Switzerland has listed energy-efficient fully-automatic and semi-automatic tabletop commercial coffee makers, which is giving an up to date market overview of the most energy-efficient models today. They can be found together with the selection criteria on www.topten.ch/gewerbliche-kaffeemaschinen for Switzerland and on www.topten.eu/commercial-coffee-makers for the European market. The list is based on the energy loss per day (as measured following DIN 18873-2:2016) which is available in the HKI-database for over 100 models [10]. After analyzing the data to check for clusters (e.g., do all machines using fresh milk have a higher energy loss?), a threshold was defined depending on the hourly capacity for coffee (cups), taking into consideration that machines with a higher capacity are more likely to use more energy (and consequentially have a higher energy loss). For the definition of the threshold, it was considered to differentiate models using fresh-milk due to the additional energy used for cooling and additional energy used for creating steam, pumping milk, etc (compare with Figure 1). However, the differences were not substantial enough and thus the general threshold was used for all models. There were several models fulfilling the criteria (e.g., automatic shut off or the possibility to set a schedule) and could be listed on Topten. With the presented threshold, models of various capacity, with and without the use of fresh milk, are represented. Further details can be found in the report [9].

Figure 2. Overview on models showing their energy loss, rated by the hourly coffee capacity, grouped by Topten and non-Topten-models.



To give an incentive for consumers to buy energy-efficient commercial coffee makers, Topten was able to integrate commercial coffee makers in the Swiss federal rebate program ProKilowatt in 2020. The program is already well known for its other categories, mainly in the commercial cooling appliances. Even though the Topten list for commercial coffee makers is a first approach to put energy-efficiency for this product category on the table, adding it to the ProKilowatt program gives it even more visibility for many stakeholders active in the same field (e.g. retailers buying commercial refrigerators for their stores, which also have a coffee take-away, will see the presentation of commercial coffee makers on Topten and look into it themselves or tell their colleague responsible for that section to do so). Topten is looking to further promote their product list to large buyers by individually contacting them, publishing articles in specialized journals and reaching out to professional associations in order to communicate with their members about the new rebates.

Portafilter espresso machines

As for portafilter machines, there is currently no data available, thus they are not yet listed on Topten. However, the testing standard DIN 18873-2 is applicable for all types of machines, incl. portafilter. There is no reason why these machines could not be measured accordingly.

Topten is striving to conduct a test series in order to get more insights of the actual energy consumption on portafilter machines as so far, they are “flying under the radar” in terms of their energy consumption. Discussions with manufacturers to obtain data were not yet successful, even though the interest in energy-efficiency improvements is there.

For a start, Topten was able to receive data of one portafilter espresso machine, which was measured for two weeks in practice. This model is located in a restaurant (open seven days a week), open for lunch as well as dinner service. Data was analysed using the opening hours (11 am to 11 pm = “open”) as well as the duration of workdays (6am – midnight = “closed”, staff is present, gets the machine ready, staff consumes a few beverages during the service preparation time, etc.). In Figure 4, the data is aggregated as the daily average over the two weeks of data, taking into account that weekends are busier. When looking at the individual power curves (one example for a Monday is shown in Figure 3), it is easy to spot that the energy consumption is to the most part (>90%) caused by keeping the machine ready (idle mode), not the actual production of a beverage (“purchase”). It is due to this fact that Topten has proposed to focus on the energy losses occurring at all times. If the energy losses are minimized, this has the highest impact on the majority of energy consumption. Note: optimizing user behaviour is an additional topic, e.g., why is the machine not completely shut off during the night.

Figure 3. Power curve of a practice measurement of a portafilter espresso machine in a restaurant (kWh/minute) for a full day.

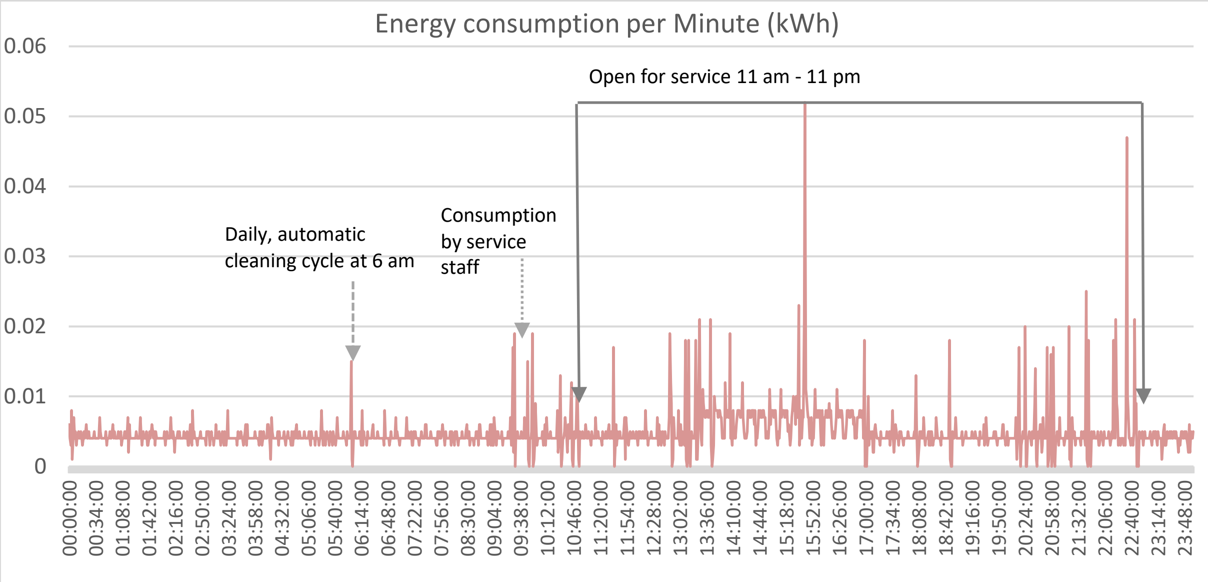
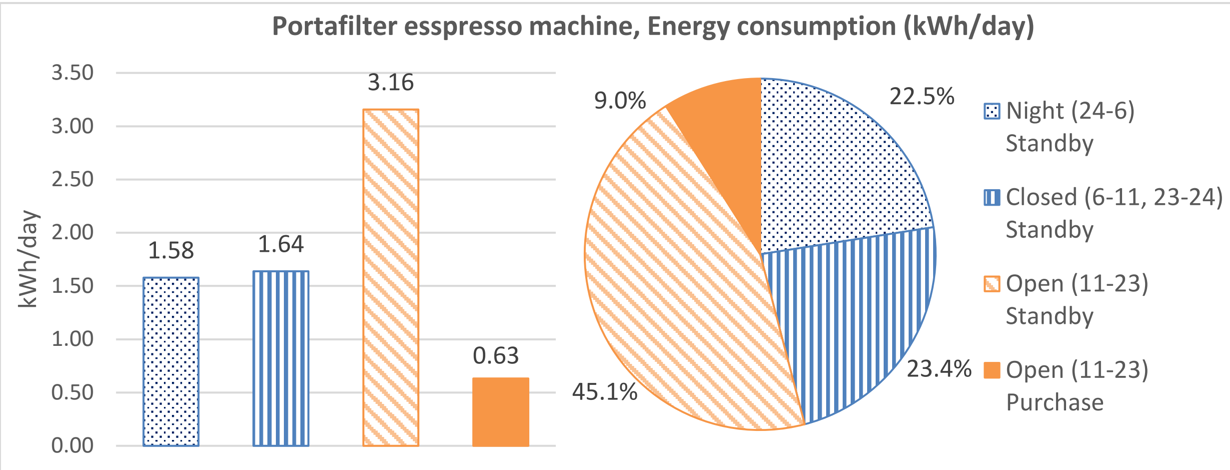


Figure 4. Practice measurement of a portafilter espresso machine in a restaurant (kWh/day) grouped for the different use phases, average per day.



Measuring standards for commercial coffee makers

As presented in [13], the available measuring standards that could be applied for commercial coffee makers, are:

- EVA EMP 3.1b «Test Protocol for the measurement of energy consumption in vending & dispensing machines, part 2: Hot and Hot & Cold drinks machines»
- DIN 18873-2:2016 « Methods For Measuring Of The Energy Use From Equipment For Commercial Kitchens - Part 2: Commercial Coffee Makers »
- ENERGY STAR: Energy Star 1.0 Commercial Coffee Brewers
- ENAK: «Testdefinition zum Kaffeemaschinen-Datenblatt»
- EN 60661:2014 «Methods for measuring the performance of electric household coffee makers».
-

[13] proposed to further evaluate EVA EMP 3.1b or DIN 18873-2, as well as to analyse the standard used for residential coffee makers, EN 60661 for its possible adaptation for the commercial sector. [9] based their

work on this study and concluded due to the simplicity of the testing method and available data for a large number of commercial coffee makers to go forward with DIN 18873-2.

DIN 18873-2:2016

The German Institute for Standardisation (DIN) provides the measurement standard DIN 18873-2 "Methods For Measuring Of The Energy Use From Equipment For Commercial Kitchens - Part 2: Commercial Coffee Machines". It targets fully automatic table-top machines and professional espresso machines (portafilter). The norm measures the energy losses per day (kWh) which includes the energy for cleaning and rinsing. It separately measures the energy loss (idle mode) of the refrigerator systems for milk. The productive energy for producing the drink (e.g. coffee) is not considered. The DIN standard does not have an energy efficiency scale nor is it used for any energy labelling.

The DIN 18873-2 is mainly used by the German Industrial Association of House, Heating and Kitchen Technology (HKI) [10]. HKI lists the energy consumption data for over 100 professional table-top coffee makers on their website. Values for professional espresso machines are currently not yet measured, although the testing norm would allow for it.

EN 60661:2014

The Swiss energy label for residential coffee makers is based on the norm EN 60661 "The methods for measuring the performance of electric household coffee makers" [3]. The label indicates the energy class which is calculated on the yearly total energy consumption. The measurement standard is separately defined for pressure coffee makers (incl. capsule/pad machines) and filter coffee makers. A test procedure for pressure coffee makers includes not only the coffee period but also the steam function, standby mode, off mode, rinsing and grinding. The procedure for filter coffee makers includes also the consumption in standby and off mode, besides the energy consumption for the coffee producing period.

CLC/TC 59X/WG 21 (pending)

CENELEC is currently working on a new standard CLC/TC 59X/WG 21 "Professional and commercial coffee machines". At the moment it is not yet possible to rely on this work, as the results are still confidential, methods have not yet been finalised and therefore no measured values are available. The COVID 19 pandemic has delayed the work and the standard has not yet been finalised. Currently, the standard is in the test phase, in which various laboratories are testing according to the draft standard and providing feedback. These test measurements could not yet be carried out due to the pandemic. It is planned to be able to conclude this feedback round in 2021, make any necessary adjustments and then submit the standard.

In the CLC/TC 59X/WG 21 standard, the goal is to be able to measure all types of machines. For this purpose, the various processes are defined individually and measured according to the machine. If individual functions, such as foaming milk, are not available, these measurement steps are omitted. The energy consumption is shown separately for each of the individual processes.

As soon as the new standard is available and measurement data is available, Topten will base its product list on these new values. However, the measurement procedure is rather complex, and it is questionable whether all manufacturers will test their models accordingly.

Comparison of methods

DIN 18873-2:2016 has the advantage that as of 2016, its measurement standard includes also professional espresso machines (portafilter), therefore it would cover all machine types. Nevertheless, measurement figures for professional espresso machines and free-standing machines are not yet found. Furthermore, the test procedure seems less demanding since the actual preparing (and vending) functions don't need to be tested. Testing only the energy loss is especially easier for professional espresso machines, where replacing the portafilter 60 times in a row and testing additional features (touch displays, vending options, built-in grinders etc.) are complicated. It is debatable if the productive energy should be considered at all for a measuring norm or if it is enough to focus on the energy loss as the relevant size. We propose to go forward with the DIN 18873-2:2016 as measuring standard and re-evaluate once the new measuring norm currently developed from CENELEC is in place.

Discussion and Conclusion

Introduction of the Energy Label for Residential Coffee Makers in the EU

An energy label is a very effective measure to help consumers recognize the most efficient coffee makers on the market. A label in the top class is an incentive for industry and trade to develop and offer energy-efficient coffee makers. These are more likely to be placed in retail stores. It further would be a useful tool for rebate programmes.

Topten recommends the introduction of an EU energy label for all types of residential coffee makers such as fully automatic machines, portioned machines (high and low pressure), machines with portafilter as well as drip-filter machines. The measurements of the energy consumption should follow the revised EN60661:2014 [3].

Ecodesign and MEPS for commercial coffee makers

Ecodesign and MEPS are powerful tools to shift appliances towards higher energy-efficiency. Due to the diverse nature of the models, it is currently difficult to name specific best or worst technologies that have the highest influence on energy consumption, further research is required on this matter.

As shown in the practice measurement conducted for a portafilter espresso machine in a restaurant (Figure 3), the majority of energy is used in ready or standby mode, not for actual production of coffees. More data is needed to show the variety of energy consumption between different types and models and applications (restaurants, offices, take-away stores, etc.), but the conclusion from just this one measurement is clear: energy losses need to be minimized, both in ready mode and standby mode.

Measures to achieve this could be:

- The adoption of Commission Regulation (EU) No 1275/2008 [6] and Commission Regulation (EU) No 801/2013 [7] on standby regulation for electrical appliances for household and office equipment.
- Mandatory timetables for the setting of on/off times to prevent machines from running 24/7. Especially for portafilter espresso machines, this is still common practice and often even recommended by manufacturers and dealers. This could also be solved with an automatic shut-off after the cleaning cycle was initiated as well as a schedule to automatically start the machine in the morning to give enough time to preheat.
- Promotion of eco-modes (reduced keep-warm-temperature) after 15min of inactivity during on-time. Some manufacturers already feature this for their machines (all types).
-

Applying the energy label from residential coffee makers to commercial coffee makers

With some adaptation, the Swiss energy label for residential coffee makers could also be used to label commercial coffee makers. As in EN 60661:2014 all phases are already described that are present also for commercial coffee makers. It could be argued that the number of beverages produced is much higher for commercial coffee makers, however this does not prevent the label to be effective. It might not exactly represent the actual energy consumption of a commercial coffee maker, especially for very busy places such as take-away cafés in a train station with lots of beverages produced daily but would still allow consumers to compare the different models based on the consumption presented. Some manufacturers already have the household energy label featured on their smaller models.

A simple adaptation would be to increase the number of beverages measured. The new measuring norm from CENELEC is heading towards this approach and can be used as the basis for a new energy label for commercial coffee machines.

Introduction of a new energy label specifically designed for commercial coffee makers

Currently, energy consumption of commercial coffee makers is not at the top of the minds for consumers. Most of them are not aware how much energy their machines are using over the lifetime. In many cases, the user is not the same person who pays the electricity bill or buys the new machine (in e.g., restaurants and bars, hotels, stores). Therefore, avoiding energy losses by shutting off the machine has no priority. An energy label can make the differences visible between manufacturers and their models and make the energy consumption a factor in the buying decision. Of course, many other factors play a role in the purchase of a commercial coffee maker:

- How reliable and durable is it?
- How large is the product range?
- How well is the service provided after the purchase for maintenance?
- How important is the price, the design and the brand?
-

Energy efficiency should be one of those factors. And a label can provide the necessary information and comparability.

Next steps

To get better insights, more practice measurements are needed to reveal the actual energy consumption of various types of coffee makers, models of the same type. It would also be interesting to see the differences for various applications (HORECA (HOtel, REstaurant, CAtering / CAfé), OCS (Office Coffee Service)) and user behaviours (aware or unaware of energy consumption with resulting behaviour).

To test the applicability of the EN 60661 for commercial coffee makers, a test series should be conducted in an independent laboratory (e.g., VDE in Germany, which is measuring many household coffee makers and some commercial coffee makers as well).

To test the applicability of the DIN 18773-2:2016 for other types of commercial coffee makers currently not available in the HKI Database (free-standing, portafilter, portioning machines), a test series should be conducted in an independent laboratory (e.g., VDE in Germany).

In the meantime, Topten will work on the promotion of its product list to bring awareness to the topic of energy-efficiency of commercial coffee makers. Topten is looking to further promote their product list to large buyers by individually contacting them, publishing articles in specialized journals and reaching out to professional associations to communicate with their members about the new rebates.

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Glossary

- CECED: former name of now APPLiA, the Association of home appliance manufacturers in Europe, Brussels.
- EnEV: Energieverordnung (Swiss Energy Directive)
- Electrosuisse: Verband für Elektro-, Energie und Informationstechnik (Association for Electrical Technology, Energy and Information Technology)
- ErP: Regulation on Energy-related Products: Regulation on Standby and Off-Mode (Comission Regulation (EU) No 1275/2008) and its amendment (Comission Regulation (EU) No 801/2013).
- FEA: Fachverband Elektroapparate für Haushalt und Gewerbe Schweiz (Swiss Association of Manufacturers of Electric Appliances for residential and commercial use)
- HKI: Industrieverband Haus-, Heiz- und Küchentechnik (German industry association for home-, heating- and kitchen appliances)
- HORECA (HOtel, REstaurant, Catering / Café)
- MEPS: Minimum Energy Performance Standard
- OCS (Office Coffee Service)
- SFOE: Swiss Federal Office of Energy
- S.A.F.E.: Swiss Agency for Energy efficiency
- VDE Testing and Certification Institute: Testing Institute from the Association of German Electrotechnology

Impact of rebate programmes: Swiss case studies

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Abstract

Rebate programmes for energy-efficient appliances are an effective measure to increase energy efficiency and reduce electricity consumption. In Switzerland, there are rebate programmes for appliances from the central government, municipalities, and electricity utilities. Various strategies are used, different types of programme schemes are applied, and several target groups are addressed. Depending on the initial situation and objectives, the focus is set on different impact mechanisms. Simple rebate programmes only target the replacement of inefficient products. More sophisticated rebate programmes address the market as a whole and aim to accelerate the market transformation and increase market transparency. This is necessary for the development of measurement methods and effective policy instruments such as energy labels or minimum energy efficiency requirements. Market transparency is also the basis for good purchasing decisions and enables fair and motivating competition between manufacturers. In Switzerland, most of the regional rebate programs are well harmonized with identical product criteria because they are in general based on topten.ch, the national platform for sustainable products. This empowers manufacturers and retailers to make effective use of the programmes (e.g. in optimizing the range of products). Communication measures and the cooperation with retailers and manufacturers are also part of the programme. Using examples from Switzerland, this article aims to provide an insight into the various types of rebate programmes. Experiences, impact mechanisms and cost efficiency are discussed based on completed and current programmes.

Keywords: Appliances, market transformation, market transparency, best available technologies, energy efficiency requirements, energy label, subsidies.

Introduction

In Switzerland, there are various rebate programmes for diverse target groups and energy-saving measures. This article describes the rebates programmes for appliances and discusses the associated experience. These programmes are classified into 6 keys categories. Their importance to the beneficiaries- the sellers or the buyers - as well as their advantage, disadvantages, risks, success factors and cost efficiency will be addressed.

Table 1. Types of programme schemes

#	Applicant	Beneficiary	User	Product categories
1	Private end users	Private end users	Private end users	Household appliances, building components, solar energy devices, electric charging stations
2	Large buyers, landlords	Large buyers, landlords	Private end users	Household appliances, building components, solar energy devices, electric charging stations
3	Companies	Companies	Companies	Office equipment, professional kitchen appliances, vending appliances, building components, solar energy devices, electric charging stations
4	Food and beverage industry	Food and beverage industry	Shops, gastronomy	Branded ice cream freezers, beverage coolers, minibars

5	Retailers, installers	Private end users	Private end users	Household appliances, building components
6	Retailers	Retailers	Private end users	Household appliances, building components

Applications from purchasers

Purchasers can be end-users (type 1 and 3), owners who make equipment available to third parties such as landlords for household appliances (type 2) or food industry for beverage coolers or ice cream chests (type 4).

- Replacement only (early replacement: e.g. halogen lamps, direct electric heaters, electric boilers, circulating pumps)
  Examples are programmes which are described on the internet: replacement of luminaires [1], energetic renewal of buildings [2], replacement of electric water heaters [3]
- New appliances <u>and</u> replacements: most of the rebate programmes for household appliances cover the purchase of new appliances as well as replacements [4]

Subsidies for retailers or installers

Subsidies can be given to retailers or installers for sales of authorised energy-efficient products. That way the purchaser gets the subsidies indirectly (type 5 and 6).

Replacement programmes

There are programmes which are restricted to subsidies for renewal and replacement measures but not for new investments.

Programme duration

Short programme duration mainly supports awareness raising and communication. It has little sustainable impact and little impact on manufacturers and trade. Long-term programmes empower all stakeholders to contribute to the impact. Actions of retailers and manufacturers need enough preparation time and planning security.

Overview on impact mechanisms of rebate programmes

1. <u>Direct effect of rebate programmes in the directly affected area:</u> Every purchase of an efficient product results in an energy saving compared to the purchase of an average product. The aim is to achieve a natural replacement cycle. Early replacement with additional costs and material input can only be recommended with good justification.

   It should be noted that the beneficiaries may be private households, professionally managed properties, and companies. The calculation of energy savings usually assumes a typical lifetime of 15 years for household appliances. The evaluations are based in each case on the difference in electricity consumption between an average and a top-of-the-range appliance. The values are based on market research and sales figures.
2. <u>Optimised purchasing behaviour</u> of professional procurers and consumers due to communication measures of the promotion programme and partners.
3. <u>Optimising and adapting the product ranges</u> of manufacturers, importers, and wholesalers due to increased demand for efficient products. Promotion programmes and Topten platforms [5] (national projects for energy efficient products) motivate manufacturers to develop better products and shops to include these eligible products in their assortments.
4. <u>International impact:</u> Rebate programmes have the most intensive impact in the promotion area but may extend their effect internationally. It is particularly effective if the directives on the European energy label and the minimum requirements can be optimised in the process.
5. <u>The impact can be multiplied</u> if other organisations and electricity suppliers take over promotion actions.

Focus of rebate programmes

- Concrete specific energy saving effect (project, replacement, purchase results in savings, effect results from before/after comparison)
- Economic promotion with considering of environmental aspects (e.g. scrapping bonus for cars); programmes with weak requirements risk to become promotions according to the watering can principle
- Promotion of market transparency, e.g. for commercial appliances without binding standards, without declaration requirements or without energy labels
- Acceleration of market transformation: support for technological leaps such as LED lamps, heat pump dryers

Case studies

The following chapters describe rebate programmes for appliances in Switzerland.

ProKilowatt: the umbrella for national rebate programmes

There are many national rebate programmes in Switzerland. ProKilowatt is the umbrella programme that organises competitive calls for tenders. More information and an overview of the funding programmes can be found on their website [7].

According to the Swiss Federal Office of Energy [6] the ProKilowatt programme reduces electricity consumption by companies in the industry and services sectors, as well as by private households, through the financial support of measures to increase its efficient use. Only replacement or renewal measures are allowed. It supports projects and programmes that meet the specified requirements and save as much electricity as possible per provided Swiss franc. The source of the funding is an electricity network surcharge which accumulates up to 50 million euros per year.

The savings are calculated conservatively based on the direct effect of the subsidized measures (difference in electricity consumption between new and old situation over life cycle). These programmes have a high cost-effectiveness of about 3 eurocents per kWh.

Discussion:

The framework of these national ProKilowatt programmes invites and empowers any organisation to apply for funding in favour of electricity savings. It opens the floor for everybody to present best ideas. The suggested projects are checked regarding feasibility and specified requirements. The focus is on best value for money. It is a great instrument to discover and implement a wide variety of energy saving measures. The challenge is to find pragmatic ways in defining effective requirements [7] and monitoring requests without obstructing successful implementation with too much bureaucracy.

Rebate programme of the City of Zurich

There are many regional and municipal rebate programmes that support energy-efficient household appliances. Most of these programmes are based on the platform Topten.ch [4] for sustainable products. In concrete terms, only appliances that are labelled on Topten.ch are eligible for subsidies. An overview of these programmes can be found on www.topten.ch/foerderprogramme. One example, the programme of the city of Zurich is described below.

In a public vote in 1991, the population of the city of Zurich decided that the electrical utility ewz should promote electricity-saving measures and renewable energies that support the energy goals of Zurich.

Figure 1. Advertising for the rebate programme for energy efficient Topten-appliances of the City of Zurich

ewz has commissioned Topten to manage the entire programme, see specific site on Topten [9]. All eligible products are listed on the Topten.ch platform.

The city of Zurich is very open regarding types of programme schemes and is interested in experimenting with it in order to find an optimal mix of instruments and to maximise its funds towards increasing energy efficient appliances. The following types are currently in the focus and refer to the types of programme schemes according to table 1 "Types of programme schemes" above.

Private applications (Type 1)

Private consumers can submit applications via an input window on the Topten.ch platform. To do so, applicants must enter information about the purchased product, their person and bank details and upload the device invoice. The process is completely electronic and simplified as far as possible. Every year, several hundred applications are made in this way, which represents approximately 20% of all subsidized devices. However, for the public, the effort required to get subsidies of some 100 euros is considerably high.

Large buyers and landlords (Type 2)

Unlike many European countries, in Switzerland the large kitchen appliances as well as the washing machines and the dryers are usually bought by the building owners and made available to the tenants. In the city of Zurich, about 90% of the residents are tenants and therefore do not buy their large household appliances themselves but are provided to them by the property owners.

Applications with many appliances from large properties can be submitted using Excel templates. Again, the process is completely electronic and simplified as far as possible. About 80% of all subsidised appliances are from applications from institutional property owners. Most of these applications are from building cooperatives and from the public sector (city as owner of real estate) although they only own about 25% of the flats. The remaining 10% of applications are from non-public real estate owners (like banks, pension funds).

We assume that this has to do with the "landlord-tenant dilemma". If landlords incur additional costs for energy-efficient appliances, this reduces their return on investment. However, the owners cannot profit from the advantage, the electricity cost savings, but only the tenants. In contrast, the public sector and building cooperatives seem to optimise the full benefit of a comprehensive assessment, purchase price plus electricity costs.

Rebate programmes can mitigate this conflict of interest by allowing not only tenants but also owners to benefit from the subsidy. For this to happen, the subsidies must be high enough to cover a sufficiently large share of the additional prices for the appliances.

Retailers and installers (Type 5)

The model of direct payment of the subsidies as price-offs in the shops with central reimbursement of the shops was tried with the rebate programme of the city of Zurich and negotiations were conducted with the national shops (online and offline). This means, no bureaucratic action (like submitting of forms) of the consumer is required to get the rebate. However, the nationwide operating shops have not been able to implement this just locally for one city, as the programming of the cash registers and customer communication are standardised nationally and special solutions for one city was too costly. Now, in conjunction with the national rebate this approach works. Both in the city of Zurich and throughout Switzerland, shops and installers reimburse the payments directly at the time of sale.

Retailers and installers are reimbursed for the subsidies based on a monitoring system that provides evidence of the subsidies.

Table 2. Rebates in the City of Zurich and in Switzerland

Product categories	**Rebates in CHF [152]**	
	Zurich	Switzerland
Refrigerators and freezers	70.-	70.-
Induction hobs	25.-	-
Dishwashers	70.-	70.-
Washing machines for apartments	70.-	70.-
Washing machines for the communal laundry	250.-	250.-
Tumble dryer	100.-	-
Comfort fans	20.-	-
TVs and PC monitors	40.-	-
Heat pump water heaters	800.-	-

Table 3. Overview on the subsidies of Zurich in 2021

Product category	**Pieces**	**Impact in kWh**
Refrigerators and freezers	530	467’400
Induction hobs	73	13’870
Dish washers	341	73’950
Washing machines for apartments	107	80’250
Washing machines for the communal	127	266’700

[152] Rebates per piece in January 2022 (1 CHF = ca. 0.95 euros = ca. 1 US$)

laundry		
Tumble dryers	221	182’325
Ventilators	7	3’500
Television sets	9	2’700
Heat pump water heaters	9	270’000
Total	**1’424**	**1’360’695**

In 2021 the City of Zurich supported 1424 appliances, generating an energy-saving impact of 1.4 million kWh. It is planned to increase the volume strongly by implementing the programme type 5 with retailers and installers.

Rebate programme Energy Efficiency in Trade

Figure 2. Advertising for the Swiss-wide rebate programme for energy efficient Topten-appliances

Initial situation and goals

On behalf of the Swiss Federal Office of Energy and ProKilowatt, Topten is coordinating the Swiss-wide rebate programme Energy Efficiency in Trade [10]. The programme started in March 2021 and will run for 2 years with a budget of 2.7 million euros. The main objective is to promote the energy efficiency of household appliances by motivating consumers to prefer efficient appliances with a subsidy.

Rebate contribution directly in the shop as a discount

The strength of this nationwide programme is its customer-friendliness and efficiency. The rebate is a flat rate of CHF 70 (ca. 64 euros) for all eligible appliances. It is to be given to customers directly at the time of purchase in the shop. For the customer, this eliminates the tedious filling out of applications. The following energy-efficient appliances with new energy labels are promoted:

Table 4. Energy efficiency requirements of the programme

Product category	Eligible classes
Dish washer	A - B
Washing machine < 8kg	A - D
Washing machine =/> 8 kg	A - B
Refrigerators	A - D
Freezers	A - D

The appliances must be declared in the shop with the new energy label, which was introduced in March 2021. Appliances with the old energy label (with classes A+++ - D) are not eligible. Besides of the direct savings of energy, this programme intends to support communication for the new energy label.

Role of the shops

1. The shops grant their customers the subsidy directly at the time of purchase as a discount for the eligible devices. The rebates are regularly reimbursed by Topten according to the monitoring.
2. The shops carry out the necessary software and cash register adjustments so that the discounts for the correct products can be granted fully automatically for all customers throughout Switzerland (online and/or in the branches). The eligible models are made available in a daily updated feed from Topten.
3. The shops provide clear and comprehensible monitoring in accordance with the requirements of the federal government.
4. The shops communicate the subsidies to their customers in a suitable form on the invoice receipts, in the shop, online and in advertising.

The implementation of these rebates in the shops needed far more efforts and time than expected and was challenging regarding shop-software, monitoring and communication. By April 2022 9 shops have joined the programme, covering the majority of all sales in Switzerland.

Figure 3. Communication of a large online shop on the rebate programme (www.nettoshop.ch/save-energy)

The approach is most successful. By the end of April 2022 more than 30'000 appliances have received rebates with a total amount of more than 2.1 million Euros.

Rebate programme "Lower electricity costs for tenants".

Initial situation and goals

On behalf of the Swiss Federal Office of Energy and ProKilowatt, Topten is coordinating the nationwide rebate programme "Lower electricity costs for tenants" [11]. The 3-years-programme has a budget of 2.7 million euros. The main objective is to promote the energy efficiency of household appliances by motivating property owners, building cooperatives and administrations to give preference to efficient appliances by means of a subsidy. The programme also aims to contribute to solving the owner-tenant dilemma. The subsidies take over part of the additional costs of the owners for efficient appliances and thus favour lower electricity costs for the tenants.

The programme is a combination of the types 2 and 5. On the one hand the large buyers and landlords can apply for subsidies, on the other hand installers can give the rebates directly and are reimbursed by Topten. By May 2022, already 20 installers provide the rebates directly.

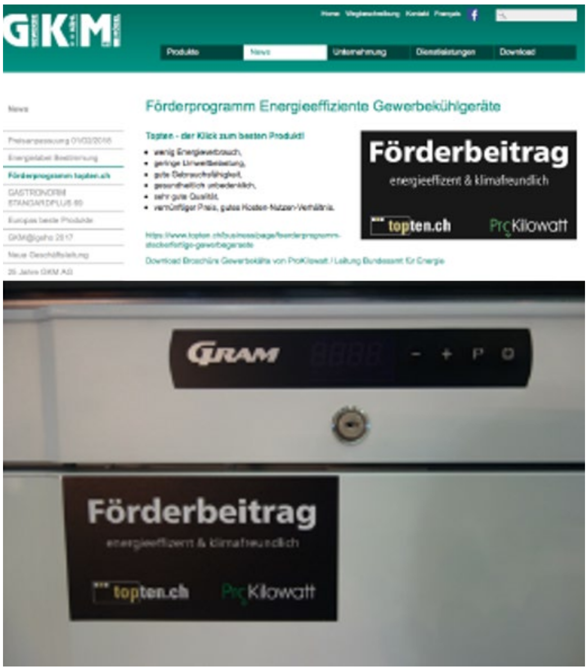
Rebate programme for professional and commercial appliances

Topten's ProKilowatt rebate programme "Energy-efficient professional and commercial appliances" supported saving of energy and money. When purchasing Topten appliances, subsidies were provided of up to 30% of the purchase price. Eligible for subsidies were appliances with the highest energy efficiency and climate-friendly refrigerant. The programme was supported by ProKilowatt under the lead of the Swiss Federal Office of Energy.

Table 5. Overview on rebates (extract)

Product category	Rebate in CHF
Beverage cooler	200
Ice cream freezer	100
Display cabinets	500
Storage refrigerators and freezers	500
Minibars	100
Drug cabinets	500
Commercial coffee machines	150
Commercial heat-pump dryers	3'000

Figure 4. Suppliers used the label for rebates "Förderbeitrag" on homepages (www.gkm-ag.ch/de/news/foerderprogramm#0) and on products.



With this rebate programme, 10'964 appliances were subsidised. By replacing inefficient models, savings of 119 million kWh were achieved. The impact achieved amounted to 160% of the original total target.

The total costs for rebates plus management summed up to 1.9 million euros. The programme had a cost effectiveness of 1.6 eurocents per kWh electricity saved.

A follow-up programme [12] with similar conditions and a budget of 1.3 million euros and the obligation to save at least 53 million kWh runs from 2021 until 2023.

National bonus programme for best appliances

The "National Bonus Programme for Best Appliances" [13] was a ProKilowatt programme implemented by Topten in cooperation with the retailers Coop, Fust, Interdiscount and Lumimart with a budget of one million Swiss francs (900'000 euros) in 2011. The bonus programme used targeted promotions to motivate customers to buy highly efficient products instead of typical models with higher electricity consumption values.

The retailers were obliged to communicate precisely which products were energy efficient and benefited of the federal rebate (claim: This rebate-promotion is supported by ProKilowatt as especially energy efficient).

For the monitoring the retailers had to report, how many eligible appliances were sold within the promotions. The monitoring was straight forward and was free of irrelevant information as who received in which outlet the subsidy. Thanks of this lean monitoring, the programme was very attractive for consumers and costs for bureaucracy could be avoided.

The total savings added up to 106 million kWh and exceeded the original target of 56 million kWh significantly (by 89%). This was possible due to the high commitment of the involved retailers, which carried out significantly more promotions and was thus able to sell far more energy-efficient appliances than expected. The electricity savings reduced household electricity bills by a total of 19 million euros over the lifetime of the appliances. The subsidy efficiency of 0.86 eurocents per kWh of electricity saved was very high and clearly exceeded the original target of 1.63 eurocents per kWh. This programme was thus extraordinarily successful both ecologically and economically.

Figure 5. Promotions of the retailers Interdiscount and Fust in their customer brochures

<u>Success factor: Steering of promotions</u>

The key factor of this programme was, that it built on the traditional sales strategy of retailers, the promotions with high discounts. Around half of the turnover in the retail trade is generated with these promotions. The role of the governmental rebates was to influence and steer the promotions.

Promotions are an essential sales tool for wholesalers, and they are carried out anyway. The selection of products for promotions usually is optimised according to the best purchasing conditions and the best sales arguments. It was surprising, however, that even with relatively small contributions, the campaigns could be directed towards specific products, here for products with best energy efficiency. The subsidies did not a priori trigger additional actions, but they directed the actions to the desired products. This was how this big lever was created, which multiplied the effect of the governmental funds.

According to the evaluation of the retailers they invested over 10 million Swiss francs in the purchase of these energy-efficient appliances and a further 7 million in the rebates, which amounted to up to 40 percent of the sales price depending on the type of appliance.

Table 6. Federal subsidies can generate high price-offs in shops

Categories	Federal Subsidies	Retailers Price-offs
Refrigerators	16.68	Up to 600
TV sets	17.13	50 - 500
Tumble dryers	69.38	Up to 1'200
Fully automatic coffee machines	17.90	200 - 500
Coffee Capsule Machines	17.90	22 - 135
Humidifier	38.27	Up to 79

The column "Federal Subsidies" shows the contribution in CHF which the retailers received per sold piece of efficient appliances. This amount was based on the agreed saving impact. The column "Retailers Price-offs" shows the discounts effectively granted in the promotions. Obviously, the federal subsidies were multiplied strongly by the retailers.

Discussion: Multiplication only with pragmatic requirements and planning certainty

This mechanism, however, only works if market-oriented and realistic criteria as well as feasible conditions are demanded. For example, the requirements for lamps were too stringent and did not match the wishes of consumers: durability and efficiency requests were only possible for extremely expensive lamps. Accordingly, it was not possible for retailers to promote this category. In addition, the wholesalers need planning security over several months. This time is needed from the investment decisions for promotions to the last sale. The wholesalers cannot plan their calculations under the risk that federal subsidies will not be paid out unexpectedly due to tightening measures. Likewise, the determination of the amount of the contribution must be bindingly fixed in advance.

Discussion and conclusions

Cost efficiency

The rebate programmes in Switzerland have a very high support efficiency of about 3 €-cents per kWh. The effect is carefully and conservatively calculated. The energy saved is significantly cheaper than newly produced energy. Economically and ecologically, it would make sense in many other countries to increase investment in energy conservation programs rather than relying on investments in new power plant capacities.

Rebate programmes can be combined with other goals. Currently, promotion programmes for household appliances are at the same time a communication measure for the introduction of the new energy label. Therefore, a lower promotion efficiency can be accepted.

Success factors

- Sufficiently strict requirements (no watering can promotion)
- Requirements coordinated or harmonised as far as possible at national or even international level (e.g. class limits of the energy labels).
- Augmentation of the impact with additional benefits (market transparency, communication, acceleration of market transformation)

- Abandonment of unnecessary sophisticated programme requirements. Even if requirements may look simple on a first glance, they may cause lots of costs, complicate the communication and can make programmes unattractive for the target groups.
- The programmes must be attractive for the target groups. It should be easy to find eligible products (e.g. on platforms for sustainable products), easy applications with no unnecessary questions and requests

Long-term innovation goals or short-term volume effects?

With funding criteria, either innovation goals or volume goals can be targeted. Innovations can be achieved with very high requirements that may not yet be fulfilled by any product at the time of introduction. However, this requires sufficiently long lead times. The effect is therefore delayed until after the first products can be sold. If immediate volume gains are sought, the criteria must be so pragmatic that the requirements are fulfilled by a minimum product offer.

Optimally, the two instruments are combined with a good mix. However, for ProKilowatt funding programmes, the volume component is mandatory, the innovation approach would require longer durations, the impact is more difficult to calculate and thus is not considered in the monitoring of the impact (conservative approach).

More innovative designs of rebate programmes

Many rebate programmes are very simple, apply for subsidies by submitting applications. This is a lot of work for the applicants, often too much to receive subsidies of some 100 euros. At the same time, processing the applications and paying out the contributions is also considerably work.

The approaches of involving the shops or installers allow for much more efficient programmes. No applications and no separate transfers are necessary (programme type 5 or 6).

It would be even more promising to work "only" with incentives, as described in the bonus programme above (programme type 6). Here, retailers were motivated with astonishingly small amounts to carry out their price-off campaigns in favour of energy-efficient products. The effect was many times greater. The argument that the impact may be more difficult to quantify and less precisely attributable to a funder should not be overweighted. We would welcome and recommend more experiments in such innovative approaches.

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The first energy labels for professional cooling appliances – lessons learnt and comparison with energy regulation for household appliances

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Abstract

The European energy labelling and ecodesign regulations for household appliances are one of Europe's greatest success stories with regards to energy efficiency. Almost two decades after the coming into effect of the first regulation for household appliances, similar regulations for equivalent appliances in the business-to-business market segment were considered to not be feasible. Arguments from opponents ranged from concerns about content safety and product functionality to claims of customized production that would make labelling impossible.

After conducting comprehensive preparatory studies, the European Commission adopted the first energy label and ecodesign regulations for professional refrigerated storage cabinets that came into effect in 2016, followed by equivalent regulations for commercial refrigerating appliances with a direct sales function that entered into force on 1 March 2021. Combined, they are expected to save an estimated 52 TWh of annual final energy savings in 2030. For professional refrigerated storage cabinets, the energy efficiency regulations have proven to be significantly more effective than any other previous type of intervention. Functionality and food safety have been maintained while technical innovations have boomed, bringing to the market in the last five years products that reach energy classes A or even A+ and giving European manufacturers an edge on the global market. Professional buyers have increased their awareness and are now able to make informed decisions and a long-term impact on pricing could not be observed. Overall, a significant market transformation has been triggered and is still taking place.

Supporting the market transformation are initiatives like Topten; over the last 20 years, Topten has collected experiences with the implementation of diverse rebate schemes, technical innovation and gained a unique insight into the long-term development of best available technologies (BAT) on the entire market.

This article will discuss the current and future efficiency potentials as well as the contributing effects of rebate programmes, focusing on four main aspects: (a) overview of BAT product development with comparison of development between household and professional appliances and current saving potentials for professional and commercial refrigeration appliances (b) effectiveness of rebate programmes, esp. with regards to multiplier effects (c) analysis of especially efficient technologies for commercial and professional refrigerators (d) potential of further energy efficiency regulations for product categories in the B2B market such as medicine cabinets.

Keywords: strategies for increasing efficiency, market transformation, standards and labels, best available technology (BAT), energy saving potential, financial incentives, ecodesign, energy labelling, commercial and professional refrigerators and freezers, natural refrigerants, green procurement.

Introduction

The European energy labelling and ecodesign regulations for household appliances have been in place for various categories since 1992, reducing the energy consumption for models of the same size by more than 70% (e.g. for refrigerators) [8]. In 2016, more than 20 years after the first EU energy label for house-hold refrigeration appliances was introduced, the first label for professional refrigerated storage appliances came into effect. The label contained a scale from A to G which was extended to A+++ to G in July 2019 and minimum energy performance standards (MEPS) that banned class G products from the market, followed by class F products in 2019 (with the exemption of heavy-duty cabinets). While some categories like static or horizontal cabinets are not within the scope, the combined savings from the most common, in-scope categories were expected to result in estimated annual energy savings of about 1.8 TWh in 2020 and 4.1 TWh in 2030 [4]. The regulation is currently in the first review process.

Regulations for refrigerating appliances with a direct sales function (commercial display refrigerating cabinets) took significantly longer in part due to necessary adjustments to B2B markets and labelling regulations for various configurations. Nonetheless, the respective energy labelling and ecodesign regulations came into effect earlier this year on March 1st 2021, covering beverage coolers, ice-cream freezers, supermarket cabinets (remote and integrated) and refrigerated vending machines. According to the preparatory study update from 2014, almost 16 million units within that scope were in stock in the EU28 market with an increase to 18 million units expected by 2030 [9]. The combined regulations for refrigerating appliances with a direct sales function are estimated to reach 48 TWh of annual final energy savings by 2030 [5].

Of special interest in both cases is the innovative approach of applying the regulation to strictly B2B (business-to-business) categories as well as the included declaration requirements, for the first time enabling buyers to realistically compare life-cycle-costs of the appliances in order to make informed investment decisions. Both regulations triggered significant market transformations, especially as efficient technologies from household refrigerators could be adopted. While no good overview of yearly sales numbers in connection to the energy label per product exists, the market development can be tracked well through observing the development of best available technologies (BAT) on the market. Topten.eu has monitored the BAT market segment for both categories since 2015 as accurately as possible given the data availability (for commercial appliances the integrated models, i.e. models with integrated system for producing cooling). The resulting data gives insights into the market development as well as further saving potentials.

Topten, the author of this paper, is an independent platform that presents the most energy efficient products on the market for household and commercial use. To be listed, products need to fulfill the selection criteria defined by Topten. They are based on existing standards and regulations and consider the product’s energy efficiency and environmental impact, resource efficiency and health impacts. The platform is used by policymakers as a source of data and science-based recommendations to develop new regulation.

Market Development BAT

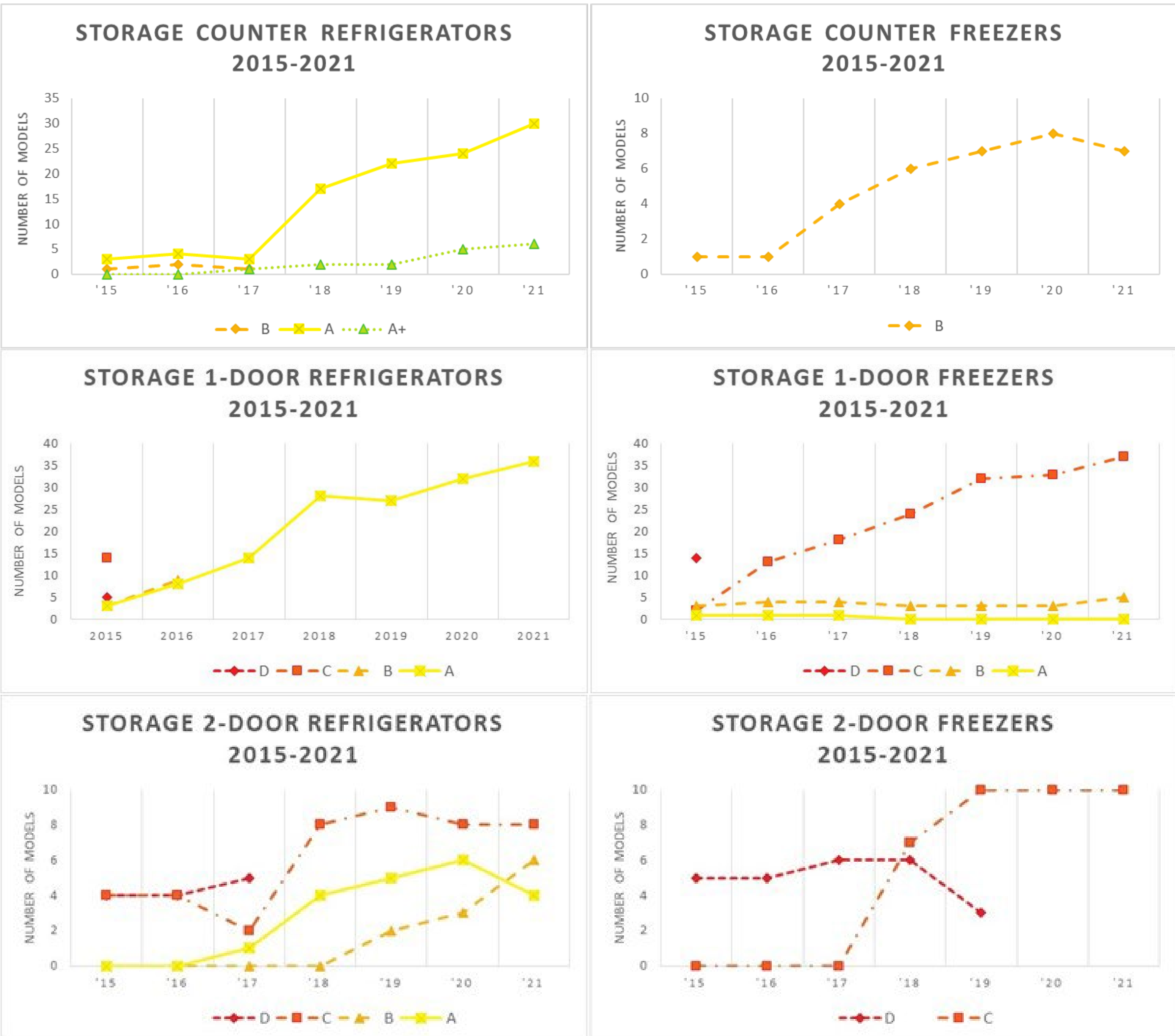
Professional refrigerated storage appliances

Professional refrigerated storage appliances are rather similar to household appliances in terms of cooling technology and basic form, though often larger, stainless steel, using forced-air cooling and occasionally containing extras like locks and more or less sophisticated monitoring and warning systems. The inside temperature ranges are similar to household appliances as well, although a large share of the professional refrigerator models on the market are also equipped to operate in especially hot environments, such as professional kitchens (so called “heavy-duty” appliances, operational at climate class 5 with 40°C and 40% relative humidity).

While in 2017, a Topten.eu market survey showed that more than 50% of the storage appliances were not yet labelled online nor contained regulation product fiches, the data availability has greatly improved by 2020 according to Topten.eu. Efficient, high quality models are more consistently labelled than low efficiency products, most likely because high efficiency can be used as marketing and sales advantage while low efficiency labels have a deterrent effect on buyers.

The graphs in Figure 1 show a significant increase in most efficient technologies (BAT models) in all six categories covered by the energy labelling for professional storage cabinets. Classes that are not listed or end in dots are not BAT technologies respectively stopped being part of the most efficient market segment due to general market improvements. Topten selection criteria are tightened every time the market allows for it. Most such changes occurred in the years 2015-2017 when data became more widely available and technologies improved due to the introduction of the new label in 2016. The graphs are based on the models listed on Topten.eu in the years 2015-2021.

Figure 5. Market development of BAT models for professional refrigerated storage appliances from 2015-2021 by category. Data & Graph: Topten.eu



For counter appliances, both graphs for cabinets in the refrigeration and freezing segment show steady market improvements, with the freezing segment showing a soft decline for 2021. However, for counter freezers this development takes place in the class B efficiency range while for counter refrigerators significant numbers of class A and even A+ models penetrate the market. A similar observation can be made for 1-door appliances: for refrigerators classes A-D were part of the high efficiency market segment in 2015 (low efficiency and data availability) while only two years later in a staggering technical development enough models had been developed and declared class A, that all lower class products could no longer be considered "most efficient"; by now, at least 36 class A models by 19 manufacturers are available on the European market. For 1-door freezers, however, the number of class B models on the market has stagnated or even decreased while the increase in efficient models is happening in the class C range. Manufacturers so far seem unable to develop further models efficient enough for classes B and A; the only class A model on the market was discovered to be falsely labelled and was re-labelled to a lower efficiency class. There are two possible explanations for these differences in efficiency classes between the professional refrigerator types:

1. Differences in EEI calculation. As the efficiency classes are dependent on the calculation factors determined in the preparatory studies and each category of professional refrigerator has its own calculation factors, it is a possibility that some of those differences are caused by the different factors for the EEI calculation of each of those categories.
2. R&D focus on popular categories. According to European manufacturers, counter and 1-door refrigerators are the most commonly sold appliances on the market for professional refrigerated

storage cabinets. As such, it stands to reason that manufacturers would focus their R&D resources on those categories first, reaching classes A or even A+ as marketing advantage.

Of course, a combination of those factors is more than likely. An exact weighting of those factors is not feasible at this point.

For 2-door cabinets, the reverse development can be observed. 2-door refrigerators of classes A and B are slowly increasing on the market. While the number of class C freezers on the market increases, no model with an efficiency class A or B has been found on the market. It would be of interest if the ongoing EU review study [2] could investigate this development to determine whether this can be attributed to the EEI calculation factors or a lack of R&D by the manufacturers.

Considering that the "standard model" on the market was defined to have an energy efficiency index of 100 (100%) in 2014 corresponding to the worst class G, the development of the BAT market segment for professional refrigerated storage cabinets has been accelerated significantly through the energy labelling and ecodesign regulation for this B2B category.

Commercial display refrigerators with a direct sales function

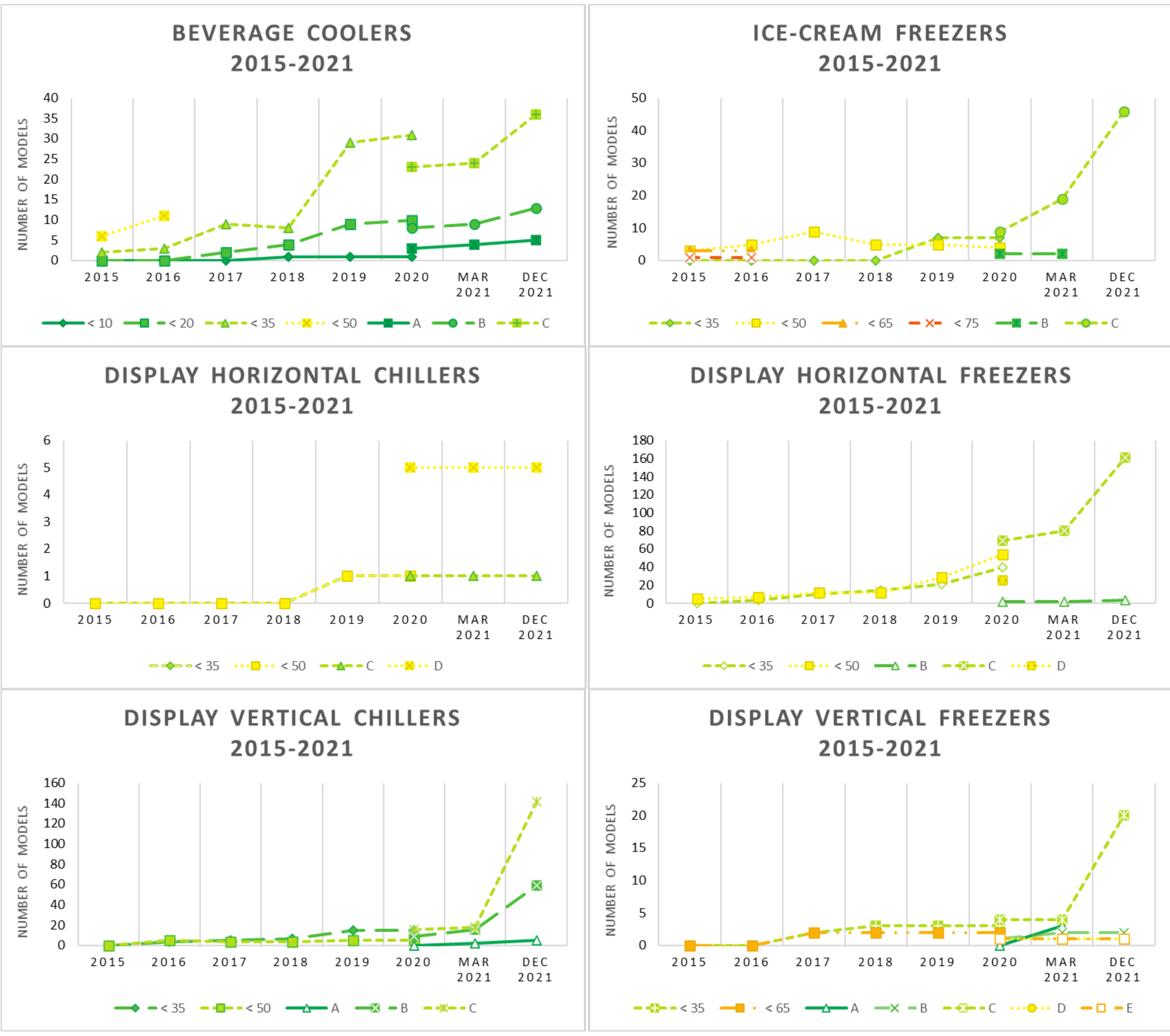
Commercial display refrigerators with a direct sales function differ more widely from household appliances and between each other. While beverage coolers are designed for non-perishable drinks, having to be able to cool down their content within a certain time due to restocking and being equipped with a night-time energy saving shut-off function, ice-cream freezers have to maintain a certain freezing temperature for their products even when placed in a sunny outside environment during summer heat waves; due to the needed local flexibility, both categories are integral (plug-in) technologies only. Supermarket appliances cover a wide range of horizontal, vertical and combined models in varying chilled and frozen temperature ranges and can be either integral or attached to a remote system with central cooling. Ambient temperatures don't pose a challenge for supermarket cabinets because supermarkets in different climate zones and seasons are widely air-conditioned and stable.

As the energy labelling regulation for refrigerating appliances with a direct sales function has only come into effect on March 1st 2021, the data sets of best available technologies on the market over the last 5 years as shown in Figure 2 are not linearly consistent. Between 2015 and 2019, the energy efficiency index (EEI) values of the BAT models were calculated using the 2014 draft calculation method. However, the draft method differs significantly from the final 2019 calculation method which includes additional factors such as factors for different temperature classes and plug-in vs. remote cabinets. As such, each graph contains two sets of data for 2020, one according to the old 2014 draft calculation, showing the EEIs of the models and one according to the final 2019 calculation method, already translated into the respective energy class. At this point, the total number of available data sets may also vary because for some products manufacturers did not make available the necessary data for the additional factors in the new EEI calculation method while other manufacturers used this opportunity to submit new products developed specifically in preparation for the impending regulation. Though EU energy labelling regulations are intentionally designed to leave class A (and if possible also class B) unpopulated at the time of entry into force in order to promote further innovation, several categories of commercial refrigerators already contained class A products in March 2021 (entry into force of the new regulation), as could be observed on Topten.eu at that time.

For beverage coolers, the number of more efficient products available on the European market started increasing in 2018, a trend that is still ongoing (Figure 2). The number of class A, B and C models on the market was already so high at the time the regulation came into effect that the Swiss government set stricter MEPS for the Swiss market at a maximum EEI of 80 instead of 100 (Switzerland normally adopts the EU energy regulation, although at times with stricter MEPS in order to further promote efficiency on the Swiss market) [12].

For ice-cream freezers, a rapid development can de observed as well. While until 2016, models with an efficiency index (EEI) of up to 75 were considered part of the high efficiency segment, with the entry into force of the new EU regulation in 2021 only the classes B and C qualify as best available technologies – with class B ranging from EEI 20 to 35, this is an increase of efficiency of over 50% compared to 2016. The high number of class C and D models available on the market from a wide range of manufacturers has also prompted the EU Commission to set stricter MEPS for this category than for the other categories in the scope of the same regulation.

Figure 6. Market development of BAT models for commercial display refrigerators with a direct sales function from 2015-2021 by category. Data & Graph: Topten.eu



The category horizontal display refrigerators shows an increase in class D models. Currently, there is no model better than class C on the market. This is a good starting position for the new label, as it allows enough potential for the manufacturers to develop more efficient technologies. It should be noted that the size indicator for supermarket appliances is the total display area (m^2) of each appliance; The total display area is part of the formula to calculate the EEI. The larger the size of an appliance (m^2) at a given energy consumption, the lower the EEI. Therefore, the market development should be observed closely over the next years to ascertain if manufacturers improve the product technology to raise the energy efficiency of their models or if this specific size indicator serves as incentive (or loophole) to simply increase the display area (glass sides) to reach higher efficiency classes through exploiting the calculation method for reaching more beneficial results.

The display horizontal freezers (including universal chests that can be set to either frozen or chilled temperatures) contain among the highest number of available models in the BAT segment of the B2B market. Notable for this data is that the numbers given in Figure 2 include series products with different sizes of a certain model type (i.e. different lengths of same technical model). In 2020, more than 100 class C and D models were provided by seven manufacturers, while in 2021 164 class B and C models were produced by five manufacturers who cover a large part of the market for this category. Most models are available in 2-10 sizes.

For display vertical refrigerators the variety of class B and C products on the market has been increasing significantly, with the first class A models entering the market. It is to be expected that the BAT segment will soon be limited to class A and B only in the Topten.eu selection criteria of most efficient products on the market for this category.

The first three class A chilled vertical products entered the market in 2020, and these products are small counter top display refrigerators. Within commercial display refrigeration, display vertical freezers are the outliers in the market development of the BAT segment. With regards to large vertical freezers, the BAT segment has remained virtually unchanged since 2017, even including class E products into the BAT segment. During our research a variety of class F models (EEI between 65 and 80) could be found; however, even intensive contact with manufacturers did not result in new data for the BAT segment to date. Whether this is due to the EEI calculation factors or manufacturers focusing their R&D resources on other categories could not be determined.

In general, two overall developments are noteworthy. First, the announcement of the new energy labelling and ecodesign regulation for these products has triggered a significant - and for this category unprecedented - market development even before the new regulations came to effect. Second, there was a sharp uptake in BAT models across all types of products in the months after the regulations entered into force in March 2021. This is due to the continued positive technical development that has started with the announcement of the regulations. Furthermore, all models have to be classified and their efficiency class be made public. This leads to better availability of information, and thus facilitates improved transparency and comparability for buyers.

In the first weeks the new energy label was not very well received. During our online research in March and April 2021, EU energy label arrows were indicated in less than 10% of the products reviewed online on the websites of manufacturers and dealers. In the meanwhile, the picture has become quite clear. There are many manufacturers that display the energy label arrow correctly. There are some manufacturers that do not yet incorporate and display the energy label and therefore do not meet the regulations. And finally, there are a few manufacturers that appear to have modified their online presence (website) to show only as little product information and data, as such that the presentation of the energy class may be deemed not necessary. That could indicate a new and to B2B specific way to circumvent the label and ultimately provide even less information than before. Those manufacturers who already comply with regulations serve as example for the industry and may advance the market towards more energy efficiency and transparency. Another intended database for product data, the European EPREL database, has been delayed [6], currently limiting data research on it.

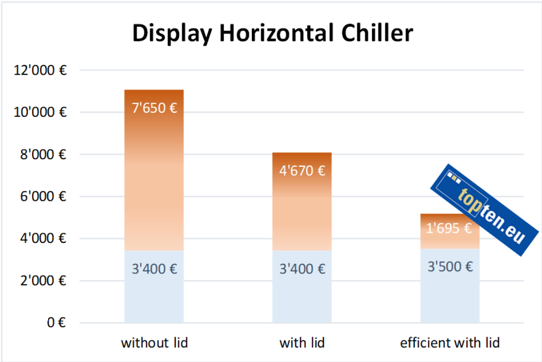
Saving Potentials of Refrigerators with a Direct Sales Function

The EU energy regulation for both household and professional appliances relies on two main concepts. Concept one is the energy labelling, set to advance the BAT segment by giving manufacturers incentives to develop more efficient products. Concept two is Ecodesign intended to “cut off” the least efficient market segment by setting minimum efficiency requirements, also known as minimum energy performance standards (MEPS). For commercial display refrigerators, it could be argued after viewing the recent development of the BAT segment that concept one has not been stringent enough in its implementation: according to EU directives the energy classes A (and where possible B) should have been set to remain empty, i.e. there are no existing products in the market in these energy classes, at the time of entry into force to provide long-term incentives for manufacturers to develop new and better technologies. However, it should also be noted that due to the lack of data availability and large untapped potentials at the time of the review study, determining appropriate levels would have been very difficult to define. The first review of the regulation after a few years of mandatory data declarations will be able to be more precise.

Regulation two is especially required for supermarket cabinets that are still often open cabinets (no doors or lids), especially in the convenience food sector. The MEPS are not likely to affect many closed glass-door appliances in the first tier but should limit the open cabinets on the market to only the more efficient technologies.

The currently available technical saving potential for appliances can be defined as the difference in consumption between the least and most efficient products on the market. As result of MEPS settings, the least efficient commercial refrigerating appliance allowed to remain on the market need to be below energy efficiency index EEI 100 (except ice-cream freezers at maximum EEI 80), and several product categories having class A BAT products available with an EEI below 10, the efficiency potential of products already on the market is 90% of the efficiency index EEI. Even presuming the average product on the market might be in the classes E and D for various categories, the current saving potential would still be around 50%. This is not even accounting for saving potential inherent to future, through even more efficient Best Not yet Available Technology (BNAT).

Figure 7. Saving potential of display horizontal chillers for supermarkets, comparing open, closed and efficient models. Data & Graph: Topten.eu



Net volume	**320 l**	**320 l**	**451 l**
Energy	4'780 kWh/a	2'920 kWh/a	1'060 kWh/a
Electricity costs*	7'650 €	4'670 €	1'695 €
Purchase price	3'400 €	3'400 €	3'500 €
Total costs	11'050 €	8'070 €	5'195 €

* 8 years, 0.2 € /kWh

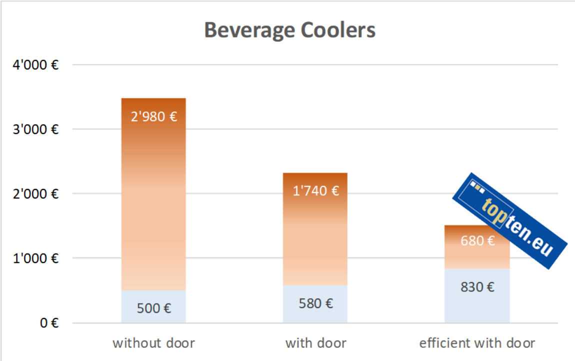
Two categories are considered in more detail in the figures below. Display horizontal chillers in supermarkets currently tend to be open, especially in the convenience food segment. Figure 3 shows that such an open appliance that is just compliant with the new MEPS easily causes electricity costs of more than 7'000 € over its assumed 8 year lifetime. An average horizontal chiller with a lid already consumes 40% less energy while a significantly larger, efficient BAT model with lid saves up to 80% energy consumption compared to the inefficient open model. Even an efficient appliance twice as expensive as the inefficient model would have a lower lifetime cost than the inefficient appliance. Many supermarkets still prefer open horizontal and vertical chillers in their stores as they fear that glass lids or doors may be a barrier for impulse buying from consumers, especially as the yearly revenue generated through a refrigerating appliance if often significantly higher than the purchase or yearly energy cost. However, studies have been published in the last years, documenting no long-term overall change in revenue between refrigerating supermarket appliances with and without doors; offsetting the additional barrier is the so called "cold-feet effect" of open appliances that causes consumers to linger less and move on faster to other areas of the supermarket which are not as cold [1].

Beverage coolers with doors have increased over the last years compared to open appliances. Manufacturers seem to have become aware of the significant saving potential available for this category which was even more significant before the coming into effect of the new MEPS on March 1st 2021. Even a larger top efficient appliance with door saves more than 75% energy compared to a smaller, but open beverage cooler just compliant with MEPS and still 60% compared to an average beverage cooler with door.

Beverage coolers are in their technology most similar to household and 1-door storage refrigerators. This makes technology transfer easy and thus results in one of the most efficient categories within the refrigerating appliances with a direct sales function.

Often, beverage coolers are purchased in bulk by large beverage companies or breweries and loaned or rented to vendors in combination with sales of their beverages. Several large beverage companies have informed us that they strive to provide their vendors with high efficiency beverage coolers as part of their company sustainability strategies. Vendors profit from lower electricity bills but often have to be convinced by the beverage companies to use coolers with doors.

Figure 8. Saving potential of beverage coolers, comparing open, closed and efficient models. Data & Graph: Topten.eu



Net volume	500 l	500 l	556 l
Energy	1'860 kWh/a	1'085 kWh/a	425 kWh/a
Electricity costs*	2,980 €	1,740 €	680 €
Purchase price	500 €	580 €	830 €
Total costs	3'480 €	2'320 €	1'510 €

* 8 years, 0.2 € /kWh

Comparison to Household Refrigerators

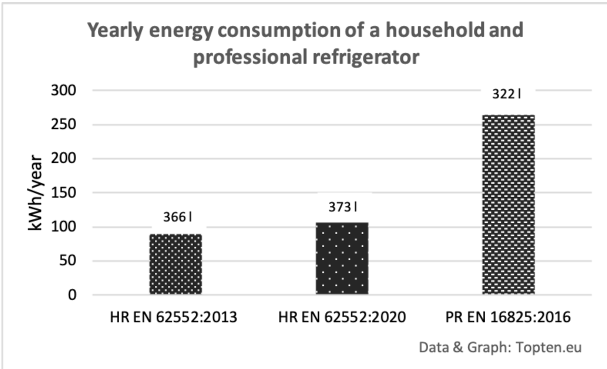
As previously stated, 1-door storage refrigerators are reasonably similar to household refrigerators in their cooling technology. While test standards differ between the two categories, the ambient conditions are similar enough to attempt a reasonable approximation in comparing the available products on the market. Main difference is the door opening sequence in EN 16825:2016 for professional refrigerated storage cabinets that is not present in EN 62552 (2013 or 2020 version) for household refrigerators. Laboratory tests by the ProCold project show a 30-50% higher energy consumption if refrigeration appliances are tested according to EN ISO 23953:2015 (with door opening sequence) as compared to EN 62552:2013 [10]; as the door opening sequence of EN ISO 23952:2015 is longer and more frequent than of EN 16825:2016, the difference in energy consumption accounted for by the different test standards between EN 62552 and EN 16825 is less than 30-50%. Figure 5 shows that the difference based on the test standard is even less for the 2020 version of EN 62552 as compared to EN 16825:2016.

Figure 5 shows the energy consumption of a BAT model household refrigerator (one of the top 5 refrigerators without freezer compartment on Topten.eu in May 2021) according to the old and new version of EN 62552 along with their net volume; in comparison, it shows the energy consumption and net volume of a 1-door professional storage refrigerator (one of the top 5 1-door storage refrigerators on Topten.eu in May 2021). The household refrigerator is class C (previously A+++), the professional refrigerator class A.

Even taking into account a very conservative 30-50% additional consumption for the EN 62552 results due to the door-opening sequence, the professional refrigerator consumes about twice as much as a comparable household refrigerator.

This means two things. One, that storage refrigerators – despite their slightly different performance requirement profile – have the potential to be as efficient as household refrigerators: only 6 years after entry into force of the energy labelling for professional storage refrigerators, more than 30 professional models by 17 European manufacturers have almost achieved the same technical efficiency that household refrigerators achieve after more than 25 years (1994 to 2021) of energy labelling, making this highly efficient technology widely available on the B2B market. The new label has obviously pushed the top segment of the market massively, profiting from existing technologies developed for household appliances. It demonstrates the huge untapped saving potential prior to the introduction of the label for professional appliances. Without the energy labelling regulation, this untapped saving potential would have remained unfulfilled. Therefore, the policy proved highly efficient. Two, significant saving potentials can still be unlocked by future phases of the regulation for professional refrigeration appliances.

Figure 9. Yearly energy consumption of a BAT household refrigerator (HR) measured according to EN 62552:2013 and EN 62552:2020 and a BAT professional storage refrigerator (PR) measured according to EN 16825:2016



It should also be noted that the "standard model" for professional refrigerators – set at EEI 100 in 2014 – had an energy consumption of 1,330 kWh/year at a time where the first class A models already existed (Topten.eu data shows the existence of three class A 1-door storage refrigerators on the market in 2015) – a saving potential of 80% between the average and best models on the market. With class F of professional refrigerated storage cabinets now banned from the market through the second tier of the MEPS, a saving potential of 75% still remains between the worst and best products on the market in 2021; even compared to a class B model, a class A BAT model saves 33% energy consumption. In 2015, the only energy classes for household refrigerators allowed on the market had a saving potential of approximately 40% between class A+ and A+++. This means that the absolute saving potential by setting more stringent MEPS in the currently ongoing review of the regulation for professional refrigerated storage cabinets is huge and should be considered carefully by the review team.

Rebates

Rebate programmes are set to increase the market share of most efficient appliances by subsidizing the initial purchase investment because more efficient appliances are often – depending on the category and more importantly the buyer – more expensive than less efficient alternatives. In Switzerland, two rebate programmes for professional storage and commercial display refrigeration appliances have been implemented in the last years with significant positive results. The rebate programmes were **funded by the Swiss Federal Office of Energy** (SFOE) and implemented by Topten Switzerland.

1. **Programme 1 (2014-2017)**: The programme had a volume of 1.3 million CHF (approx. 1.2 million €) and resulted in **total energy savings of 54.6 GWh**. Despite a slow start, 5,955 products were subsidized over the four year programme duration, surpassing the target by 22%. The rebate programme had an effectiveness of 2.4 Rp./kWh, which is **2.2ct/kWh**.
2. **Programme 2 (2018-2020)**: The programme had a volume of 2 million CHF (approx. 1.8 million €) and resulted in **total energy savings of 118.5 GWh**, almost twice the original target. The rebate programme supported the purchase of 10'955 highly efficient appliances over the three years programme duration. The rebate programme had an effectiveness of 1.7 Rp./kWh which is **1.5ct/kWh**.[153]

Both programme concepts were originally calculated with higher cost per kWh; however, large number of submissions for product categories with especially high savings significantly improved the final cost effectiveness of both programmes. The idea behind these programmes by the SFOE is that the saved kWh should be cheaper than the purchase of one.

After a rather slow programme start, the participation of investors has increased steadily over the duration of both programmes. Feedback by buyers indicates that the continuousness of the programmes is of special

[153] 1 Rp. = 0.01 Swiss Francs | 1 ct. = 0.01 EUR

importance, allowing dealers and buyers to know about the programme and allowing for long-term planning which is especially important for large buyers and companies. A third programme was started in 2021 and is scheduled to continue until 2023. Buyers and dealers now actively encourage manufacturers to develop more efficient products to list on Topten so that they may become part of the rebate programme.

One often discussed aspect of rebate programmes is the so called "deadweight effect", referring to people receiving rebate financing despite the fact that they would have chosen the high efficiency product anyway. However, most large buyers confirm the qualification of certain products for the rebate programme before the purchase, demonstrating that their purchase decision is significantly impacted by the financial subsidy. In addition, the savings of the programme are calculated by comparing an average market model with a high efficiency model. This allows to support the decision of both, potential buyers who would buy low efficiency products as well as those who already buy high efficiency products.

Of greater relevance is the multiplier effect, which is described here based on feedback from participants in the Swiss rebate programmes from 2014-2020. As already mentioned, buyers and dealers actively encourage manufacturers to develop and list high efficiency products that fulfil the strict selection criteria for the rebate programme which is especially effective in the case of larger buyers. Those technological innovations are then often implemented in the wider product range of the manufacturer and sometimes imitated by other manufacturers, leading to a significant multiplier effect. Dealers procure larger numbers of high efficiency products because they anticipate higher sales numbers for those products. They advertise the programme on their websites and advertise it to buyers during sales conversations. Large buyers adjust their procurement accordingly, sometimes at national level. The overview over available BAT products and higher efficiency in the market allows policy makers to make more informed decisions and set tighter MEPS, further increasing the market efficiency. All those effects increase the effectiveness of the rebate programmes by large factors, though they cannot be measured concretely.

Efficient Technologies

To understand the fast market transformation on the B2B market for professional storage and commercial display refrigerated appliances on the European market in the last few years and further potentials for the future, an examination of the factors that particularly contribute to the energy efficiency of the appliances is useful. There are a few components in the refrigeration cabinets that especially contribute said efficiency of the appliances. The most effective and common technologies will be introduced here, based on discussions of Topten.eu with manufacturers and intensive product research.

1. **VS compressors**. Variable speed compressors are designed to continuously adjust the motor speed to match the output required instead of running continuously at full load like conventional compressors. With less rotations per minute during low demand periods, the energy consumption is correspondingly significantly lower. Example found in the field: the horizontal supermarket freezers (respective universal chests) of a certain product series are available in both configurations either with a regular or variable speed compressor. Of the eight products of each series (different sizes of the same model), seven of the products with VS compressor were one energy class better despite otherwise containing identical technology.
2. **Insulation**: The thickness of the insulation determines how much of the internal temperature the appliance retains without having to compensate it with the cooling apparatus. The better the insulation, the more efficient the product. This is especially relevant for storage refrigerated cabinets where aesthetics is of secondary importance compared to household refrigerators.
3. **Double or triple glazing or air curtains**. As for windows in buildings, double or triple glazing in the door and other glass display areas will retain more of the internal temperature, making this an important aspect of insulation. Similarly, open appliances use air curtains to limit the cold air leaking from the open sides. Some manufacturers have come up with double or triple air curtains to increase its effectiveness and efficiency. Some manufacturers claim being able to reach the efficiency of glass door cabinets through the implementation of advanced air curtain systems; Topten.eu observations at recent trade shows support that the most efficient open cabinets with advanced air curtain systems reach the efficiency of average glass door cabinets, although not yet of BAT model glass door cabinets.
4. **Water loop or remote systems**. In remote systems, the cold is "produced" centrally and transported throughout the cooling system to the connected appliances. In reverse, the waste heat is used in other areas such as room or water heating. A hybrid version for plug-in appliances exists in

the form of water loop systems. While the appliances are integral, they are connected to a water system, that transports the waste heat to other parts of the building system where it can be used and loops the cold water back to the appliance. The disadvantage seen in this system by buyers is that the plug-in appliances lose their flexibility through the fixation in such systems, as generally the advantage of plug-in appliances in large stores with existing remote systems is their flexibility that allows them to be re-arranged weekly in accordance with weekly product offers.

5. **Green refrigerants**. The European F-Gas regulation [3] promotes the use of refrigerants with a low global warming potential in integrated and remote systems by phasing out high GWP refrigerants in several steps (e.g. ban on refrigerants with GWP above 150 by 2022 for integrated refrigeration cabinets). As a result, manufacturers of commercial and professional refrigerating appliances have started to switch from using refrigerants such as R404a with a GWP of 3,922 or R134a with a GWP of 1,430 to low GWP refrigerants such as R290 and R600a, both with a GWP of 3. A GWP of 3,922 means that R404a has about 1,300 times as much global warming potential as R290. As leakage is a widely common phenomenon in cooling systems [7], the use of green refrigerants significantly reduces the impact on the environment. Though not strictly related to the energy efficiency of a product, R290 and R600a are highly flammable HCs and as a result have long been restricted to 150g per cooling circuit for product safety. As multiple cooling circuits are expensive, manufacturers have aimed to make the most of the available refrigeration in single circuits, making the models often significantly more energy efficient than equivalent high GWP (non-flammable) refrigerant models with no refrigerant restrictions.

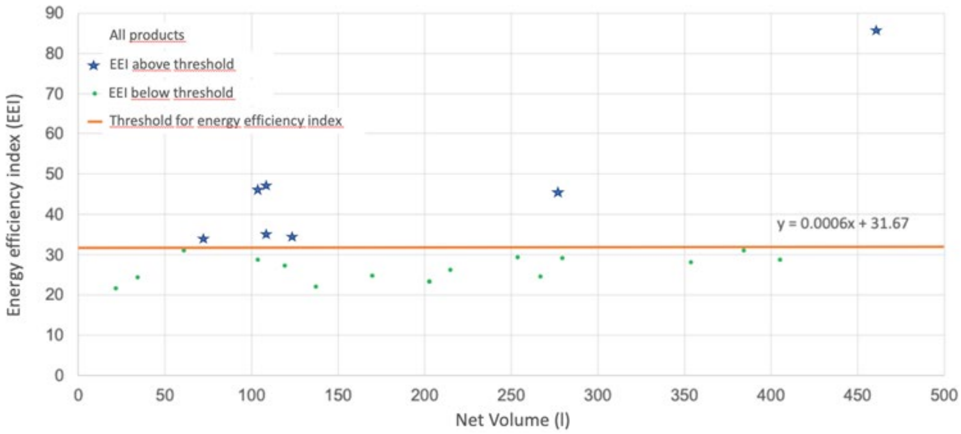
Further B2B Categories

The current regulations for the B2B categories commercial and professional refrigerators cover the products with the highest market share. However, further categories also present significant saving potentials and could be considered for future energy regulation. E.g. refrigerated medicine cabinets can be found in every pharmacy, hospital and doctor's office and are used to store medicines and vaccinations that need to be refrigerated. Especially under the current COVID-19 pandemic circumstances the number of refrigerated medicine cabinets on the market has likely increased significantly. Refrigerated medicine cabinets are different from other similar equipment, such as laboratory grade refrigerators and freezers, ultra-low temperature freezers, blood storage refrigerators or refrigerated plasma storage equipment, because they are set for different internal temperatures and are covered by different existing test standards. From professional refrigerated storage cabinets, refrigerated medicine cabinets differ mainly by the accuracy of the inside temperature setting between +2...+8°C and advanced warning systems, though the latter are regularly applied to storage refrigerators as well. Topten has compiled a study on refrigerated medicine cabinets on behalf of the Swiss Federal Office of Energy (SFOE) to identify data reliability and saving potentials [11].

In order to have comparable data, a common test method has to be selected. For refrigerated medicine cabinets, both EN 16825:2016 "Refrigerated storage cabinets and counters for professional use – Classification, requirements, test conditions" or DIN 58345:2007 "Refrigerators for drugs – Definitions, requirements, testing" could be considered. As EN 16825:2016 does not currently test for the accuracy of the pre-set inside temperature, something that is of vital importance for sensitive medicine and vaccinations, DIN 58345:2007 can be considered hitherto the best basis for a European test standard. No official European test standard has to date been defined or commissioned. A request to CEN-CENELEC is currently being prepared.

Comprehensive online research revealed 40 refrigerated medicine cabinets with declared energy consumption. Out of those declarations, 27 energy consumptions were declared according to DIN 58345:2007, while the rest did not specify the test method. In order to determine the efficiency of the products, an EEI value was calculated using the formula for EEI calculation for professional storage refrigerators. Where net volumes were not declared, a factor of 0.77 was applied to determine net volume, the average factor that corresponds to the ratio between gross and net volumes of appliances that declared both values. The available data is plotted in Figure 6. The resulting linear function is nearly horizontal.

Figure 10. EEI and net volume of the refrigerated medicine cabinets with declared energy consumption values. Data & Graph: Topten.ch



In order to determine the saving potential of refrigerated medicine cabinets, a market average appliance has to be identified as reference. Taking into account that with no mandatory declaration, manufacturers of such appliances obviously only declare values for the most efficient products, however, no average market appliance could be derived from the collected data. In the absence of other options, an average model could be considered at the level where the EU preparatory study for professional refrigeration appliances set the standard model for storage refrigerators at EEI 100. As medicine cabinets are not yet part of the scope of current EU regulations, the positive developments shown for the development of the BAT segments for storage refrigerators cannot be assumed for medicine cabinets. Allowing for some transfer of efficient technologies and being extremely conservative, the market average appliance for refrigerated medicine cabinets is set at EEI 75 / class D. The criteria for the BAT market segment is set at EEI 35 in accordance with Figure 6 and the energy class threshold for storage refrigerators.

Table 2. Calculating the saving potential of refrigerated medicine cabinets per year

	Average EEI	**Average Volume**	**Average annual energy consumption**
Market average model	75	195 litres	697 kWh/year
Average BAT model	26	195 litres	273 kWh/year
Saving potential	49		455 kWh/year

Table 1 shows that the yearly saving potential of a medicine cabinet is 455 kWh or 6,825 kWh over the assumed product lifetime of 15 years that is communicated by manufacturers. That translates to saved energy costs of 1,365 € over the product lifetime (at an estimated price of 0.2€/kWh – real prices vary on a national level). As all estimates are very rough and extremely conservative, the true saving potential is likely a lot higher.

It has often been argued that energy efficiency cannot be applied to refrigerated medicine cabinets because it risks the safety of the content and consequently human health. However, the same argument was prominently made for refrigerated storage cabinets and food safety. The last five years have shown that even at highest efficiency of existing products (classes A and A+), food safety and performance are not negatively impacted at all. In addition, various methods of monitoring and warning systems are installed in case of a system failure – which is independent of high or low product efficiency. As such, with a test method that tests the performance of the refrigerated medicine cabinets as well as their energy consumption, there is no reason why the saving potentials of this growing category should not be realized.

Conclusion

The energy regulations for professional storage and commercial display refrigerated appliances proved to be highly effective. Huge saving potentials have been realized on a technical level as demonstrated by the development of BAT models on the market and highly efficient models are moving into broad market spectrums instead of remaining small (and expensive) elite segments. The new energy labelling and ecodesign regulation for commercial display refrigerators with a direct sales function has triggered a significant market development even before the new regulations coming into effect but especially after the coming into effect.

Further saving potential exists for commercial display refrigerators where the energy regulation is fairly recent and even average models have a saving potential of about 50% compared to best models on the market and for professional storage refrigerators despite the already impressive development of the last 6 years. Main contributing technical aspects towards appliance efficiency are compressors, insulation, quality doors or air curtains, remote systems and green refrigerants. Additional categories such as refrigerated medicine cabinets should be added to the scope of the regulations in order to optimize their impact.

Rebate programmes have proven to be highly effective policy tools to boost market transformation, resulting in less cost per kWh than the purchase price of the kWh would be. Of greater effect is the multiplier effect of rebate programmes, providing incentives to manufacturers to develop better technologies and to dealers to adjust their product range and highlight efficiency as important aspect in sales discussions.

In conclusion, energy labels and minimum requirements have proven to be effective tools on the B2B market, by giving innovative manufacturers an edge, dealers a new sales argument and investors the chance to make truly informed decisions.

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Opportunities and Limits of Regulating Commercial Kitchen Appliances

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Abstract

Commercial kitchen appliances sell in relatively low volumes compared to household appliances, but their energy consumption accounts for a visible share of a country's electricity demand. Which is why the EU is considering whether to introduce ecodesign requirements and energy labelling for this product group. A single deep fat fryer or professional cooking kettle uses as much energy as three entire households (over 10'000 kWh per year).

Organizations such as HKI with the CERT commercial catering equipment database for self-regulation in Germany, ENAK in Switzerland, and the EPA with the ENERGY STAR program in USA and Canada are developing measurement methods and making energy data available for calculations and comparisons. This work happens at national level and the methods are not compatible with one another. This paper illustrates the different sets of energy performance data on the example of deep fat fryers.

The authors in this paper explore two approaches for ecodesign requirements they believe could be implemented with relative ease. The first proposal are minimum requirements regarding technical features like insulation or controls that avoid energy waste. The second proposal is to demand of the suppliers that they provide helpful information for staff training on how to operate the equipment economically. The authors draw on results of comparative measurements with and without insulation carried out by a manufacturer and HKI member for the purpose of this paper. They also consider findings from a recent study by ENAK on the energy efficiency of 16 commercial kitchen appliances in Switzerland.

Introduction

The energy consumption of commercial kitchen appliances has been the focus of organizations like HKI in Germany or ENAK in Switzerland for decades [1][2]. They have been developing measurement methods for energy consumption and making data available for calculations and comparisons. In 2019 and 2020, the Swiss Federal Office of Energy (SFOE) commissioned three studies on the energy efficiency of commercial kitchen appliances (one of them written by ENAK) [3][4][5]. Then, during 2021, professional dishwashers and professional cooking appliances were shortlisted in the preparatory study for the ecodesign and energy labelling working plan 2020-2024, which means that ecodesign requirements and an energy labelling regulation might be adopted for these product groups in the coming years [6]. In the final working plan 2020-2024, priority was given to professional dishwashers [7]. For professional cooking appliances, the expected timeline will be longer. A scoping study is foreseen in order to define which product types exactly should be studied further. Afterwards a dedicated study of about two years would be conducted. Should ecodesign requirements and maybe an energy label actually be implemented, this can probably be expected earliest in the year 2027.

For this paper, authors from SFOE and HKI joined forces to think about opportunities and limits of possible ecodesign and energy labelling regulations for professional cooking appliances. Part 1 describes the existing and planned EU regulations with relevance to foodservice equipment. This serves as an introduction for those less familiar with this kind of regulation. Part 2 illustrates energy data from three product databases maintained by HKI in Germany, ENAK in Switzerland, and the EPA with the ENERGY STAR program in the USA and Canada. The available data for deep fat fryers is shown. In part 3, the authors elaborate on two aspects that can be implemented in the framework of ecodesign regulations: The first aspect is setting minimum requirements regarding technical features like insulation or controls that avoid energy waste. The second aspect is information for kitchen staff so they can be easily and better trained and know how to operate the equipment economically. The authors were interested in these two aspects because they might be a pragmatic approach for this complex product group. The suggested requirements could be implemented with relative ease.

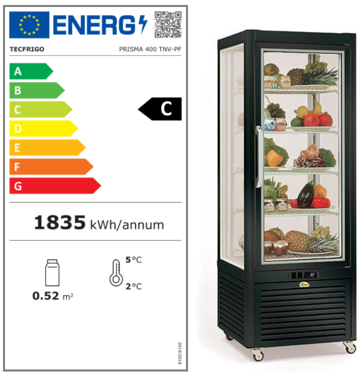
Part 1 – Ecodesign requirements and energy labelling

Existing ecodesign requirements and energy labelling for foodservice equipment

Commercial and professional refrigerating equipment is currently subject to four EU regulations regarding ecodesign requirements and energy labelling [8][9][10][11]. The regulations differentiate between three main types of refrigerators and freezers, namely “professional refrigerated storage cabinets” and “blast cabinets” on the one hand, and “refrigerating appliances with a direct sales function” on the other hand. This second group of “refrigerating appliances with a direct sales function” stands for display refrigerators and freezers for supermarkets, bakeries etc. (including serve-over counters), beverage coolers, ice cream freezers, gelato-scooping cabinets, and cold vending machines. Figure 1 shows two examples of energy labels for a display refrigerator and a professional refrigerated storage cabinet.

Figure 11. Examples of energy labels for commercial refrigerating equipment

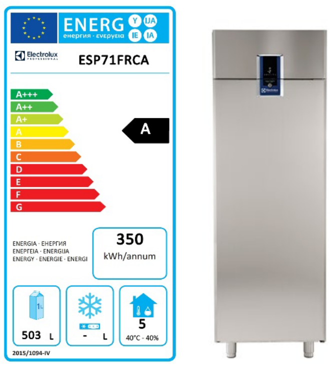
Refrigerating appliance with a direct sales function



Source: EPREL / Tecfrigo

Link to EPREL: https://eprel.ec.europa.eu/screen/product/refrigeratingappliancesdirectsalesfunction/533793

Professional refrigerated storage cabinet



Source: Electrolux Professional

EPREL registration is obligatory. Because of the older label there is no QR code with a link to the product information on EPREL.

Product groups that have an energy label must be registered in the European Product Registry for Energy Labelling (EPREL). The new labels since 2019 (design with black frame) contain a QR code that links to the publicly available product information on EPREL. The older labels (design with blue frame) do not have a QR code and the registered models do not have a publicly available product site and link. Since labels are revised periodically (after about five to ten years), QR codes for these products will be introduced at some point. Product groups without energy label are not contained in EPREL. This is the case for blast cabinets which are only covered by ecodesign requirements.

Ecodesign requirements are typically structured in two chapters: 1) energy efficiency requirements and 2) product information requirements. In recent regulations another chapter has been included on resource efficiency requirements. This last chapter concerns spare parts, repair information and recycling. It is not of concern for this paper and will not be further mentioned. Blast cabinets are a somewhat unusual case, and it was the first introduction of ecodesign in the foodservice equipment sector. Due to lack of comprehensive product data at the time of making the ecodesign regulation, a product information requirement was set to make mandatory the publication of their energy consumption. Namely the energy consumption (in kWh per kg of foodstuffs per standard temperature cycle), the standard temperature cycle, meaning from which temperature in °C down to which temperature in °C foodstuffs are intended to be cooled and in how many minutes, and the full load capacity of the cabinet (in kg of foodstuffs) must be published.

For the questions discussed in this paper, it is important to know that the chapter on product information requirements can cover a wide spectrum of different aspects. For example, among other information, manufacturers of refrigerating appliances with a direct sales function are required to publish the following information:

- the recommended setting of temperatures in each compartment for optimum food preservation
- an estimation of the impact of temperature settings on food waste
- for integral cabinets: 'If the condenser coil is not cleaned [the recommended frequency for cleaning the condenser coil, expressed in times per year], the efficiency of the appliance will decrease significantly.'
  -

These examples show that product information requirements can address recommendations for reducing food waste or maintenance instructions for saving energy.

A study for the review of the regulations for professional refrigerated storage cabinets and blast cabinets started in January 2021 [12].

Ecodesign and Energy Labelling Working Plan 2020-2024

During 2021, the European Commission specified the next Ecodesign and Energy Labelling Working Plan (called '2020-2024' because it replaces the previous working plan 2016-2019). The working plan defines when existing ecodesign and energy labelling regulations shall be reviewed, and it foresees new product groups for which such regulations could possibly be introduced next. A preparatory study for the working plan 2020-2024 was completed in May 2021 [6]. The study shortlists professional cooking appliances, professional dishwashers and professional laundry appliances to be of interest. These and seven other product groups (not related to commercial kitchen and laundry equipment) are recommended to be studied in detail for potential regulation in the next years. The European Commission then received feedback from a public consultation ('have your say') and a closed Consultation Forum that mainly consists of Member States representatives and interest groups (associations, consumer and environmental organizations etc.). The final working plan 2020-2024 was published on 30 March 2022 [7], giving priority to professional dishwashers and professional laundry appliances.

Professional dishwashers

Professional dishwashers are a product group with priority in the working plan 2020-2024. It should be relatively straightforward to introduce ecodesign requirements for professional dishwashers (undercounter and hood types), according to the preparatory study (Task 4, p. 33):

"Professional dishwashers, together with professional laundry appliances, were subject of a preparatory study in 2011, which concluded that these products met all the eligibility criteria, but that there were no suitable test standards. After Consultation Forums in 2013 and 2014 it was decided to wait with measures until such test standards were developed. Following a standardisation request, CENELEC standard EN 63136:2019 was developed for laboratory testing of undercounter and hood types, estimated to represent 95% of unit sales and up to 75% of energy and material consumption of commercial dishwashers in the EU."

Conveyor-type dishwashers will likely be excluded from the scope.

Professional cooking appliances

For professional cooking appliances, the situation is less straightforward. The scope is yet to be defined, and there are no EN standards available to date. CLC/TC59X/WG18 is working on a European standard for combination ovens for professional use. For other professional cooking appliances, no standardisation work is going on at the moment. The equipment types considered in the preparatory study are (Task 4, p. 35-36):

- Ovens
- Hobs and grills
- Fryers (deep fryers)
- Bain Maries
- Bratt pans
- Pasta cookers
- Range hoods

"It is a very large and diverse product category, containing a large number of appliance types and variants. However, the majority of potential energy savings comes from ovens, hobs/grills and fryers (94 PJ/year, 80%), which is more homogenous though still with variants. However, the saving potential is interesting even if the scope is reduced, due to generally high usage pattern."

"European measurement standards are not available or in development for all equipment types, but there are other standards available such as German DIN standards, French NF and US ASTM standards, which may assist in developing transitional methods and standards. (…) A preparatory study should include a proper scoping, which may reduce the number of appliances to include in the study e.g. by focusing on ovens, hobs/grills and fryers."

The preparatory study recommends that a scoping study for professional cooking appliances will be performed before conducting a full dedicated study for ecodesign.

Part 2 – Energy data from HKI, ENAK and ENERGY STAR

Overview of the three initiatives

HKI

The energy consumption of products is increasingly becoming the focus of interest of customers and policy makers. For this reason, HKI Industrial Association for House, Heating and Kitchen technology, together with its members, set the goal to create a platform for information for the objective comparison of energy-related product data. The database HKI CERT commercial catering equipment is the central platform for information on the energy consumption of appliances of leading manufacturers of catering equipment in Germany. Through the database operators, vendors, planners and other interested parties gain access to a key medium for information and for the comparison of energy-related data. Necessary data is collected by certified laboratories on the basis of applicable DIN standards to ensure accuracy and comparability for all registered devices. The applicable DIN standards are DIN 18872-3 and DIN 18873-1 1 to DIN 18873-21.

ENAK

ENAK is an alliance of planners, end users, engineers and manufacturers in the area of hotels, gastronomy and catering in Switzerland. All work on a voluntary basis and with the objective to promote energy-efficient appliances and their rational use. ENAK advocates a uniform declaration of resource consumption such as energy, water or chemicals. They operate a database with appliance data. In contrary to HKI and ENERGY STAR, their product database is not linked to national standards, as Switzerland does not have any that concern the energy consumption of commercial kitchen equipment. Therefore ENAK develops their own test definitions and worksheets. In the online planning tool ENAK-Tech, the energy and water consumption of appliances can be compiled under consideration of the individual load profile.

ENERGY STAR

ENERGY STAR is a program for energy efficiency in the USA and Canada. It is a government initiative from the U.S. Environmental Protection Agency (EPA). Their goal is it to provide simple, unbiased and credible information to consumers as well as businesses, which will help them by their purchasing decisions of electric appliances. To earn the ENERGY STAR label, products must meet minimum energy efficiency criteria. The certified products include household appliances, commercial appliances and industrial appliances. ENERGY STAR requires all products to be third-party certified. Products are tested in an EPA-recognized laboratory on the basis of applicable ASTM standards and reviewed by an EPA-recognized certification body.

Table 3. Overview of the covered product types by each initiative

HKI (Germany)	ENAK (Switzerland)	ENERGY STAR (USA/Canada)
• Refrigerated display cases for food	• Multifunction turbo ovens	• Commercial Coffee

distribution • Convection steamers • Commercial coffee machines • Deep fat fryers • Convection ovens • Tilting frying pans and stationary frying pans • Tilting pressure braising pans and stationary pressure braising • Multiple deck ovens • Regenerating systems • Cooking zones • Ice machines • Beverage coolers • Ovens • Microwave combination ovens • Point of use water dispensers for cooling and carbon dioxide enrichment • Double jacketed boiling and quick boiling pans • Kitchen Machinery • Noodle cookers • Wafflebakers • Frying and grilling appliances • Crepe and Poffertjes-Bakers • Heated plate dispensers	• Cookers • Cooking kettles and pans • Combi steamers / Confectionery machines • Fryers / pasta cookers • Bain-maries and heated display cabinets • Refrigerators • Blast chillers/ shock freezers • Ice machines • coffee machines • Dishwashers • Washing machines / driers	Brewers • Commercial Dishwashers • Commercial Fryers • Commercial Griddles • Commercial Hot Food Holding Cabinets • Commercial Ice Makers • Commercial Ovens • Commercial Refrigerators & Freezers • Commercial Steam Cookers

Choice of data for analysis

We searched for a category that is covered by all of the three initiatives and has a high number of models registered. This turned into a challenge. The product categories of the three initiatives are quite different. Which does not leave many options for comparison. For example, commercial coffee machines in USA and Canada are very different from commercial coffee machines in the European Union and Switzerland and therefore cannot be compared. Another obstacle was the data availability, as for most categories only few data was available.

In the end, we chose to analyze data for electric commercial deep fat fryers. Thereby it is to mention that the "deep fat fryers" from the HKI database are actually multifunctional cooking appliances for boiling, frying and deep-frying and represent only one brand. ENERGY STAR had 60 electric and 86 gas-powered models from totally 11 different brands in their database for deep fat fryers, whereas for HKI and ENAK gas-powered models are not relevant.

Table 4. Number of models and brands for deep fat fryers (September 2021)

Appliance type	HKI	ENAK	ENERGY STAR	
Deep fat fryers	14 models 1 brand	27 models 5 brands	Electric: 60 models 6 brands	Gas-powered: 86 models 8 brands

Measured parameters for deep fat fryers at HKI, ENAK and ENERGY STAR

Each initiative has different measurement methods and are therefore not comparable. HKI, ENAK and ENERGY STAR each use their own specific set of measured values (see Table 3), there are no similar parameters between the different databases.

Table 5. Overview of measured parameters for deep fat fryers in the three schemes

HKI	**Energy consumption preheat cycle (in kWh)** to heat up from 23 ± 3 °C to 175 ± 5 °C **Energy efficiency preheat cycle (in %)** **Energy consumption for hot holding cycle** of over 2 hours at 175 ± 5 °C **(in kWh)** **Energy consumption for hot holding cycle** of over 2 hours at 175 ± 5 °C per kilogram **of cooking oil (in kWh/kg)** **Energy consumption deep frying cycle** at 175 ± 5 °C (**in kWh)** **Energy consumption deep frying cycle per kilogram of frozen french fries** at 175 ± 5 °C **(in kWh/kg)** **Production volume per hour** at 175 ± 5 °C **(in kg/h)** **Total energy use (in kWh)** **Total energy use per kilogram deep frozen chips (in kWh/kg)**
ENAK	**Maximum power consumption (in kW):** the highest measured power consumption during the test **Heating process (in kWh):** a) energy needed to heat up from 24°C to 170°C and b) energy needed to heat up from 130°C to 170°C **Standby consumption (in kWh):** Energy consumption during 3 hours standby mode at 130°C (starting measurement at 170°C) **Deep frying (in kWh):** Energy needed to fry x kg frozen fries (-18°C) for 5 minutes; 7 liters oil = 0.8 kg fries, 12 liters oil = 1.5 kg, 17 liters oil = 2.0 kg
ENERGY STAR	**Cooking Energy Efficiency (in %):** The quantity of energy input to the food product (i.e. French fries) during the cooking process, expressed as a percentage of the quantity of energy input to the fryer during the heavy-load tests. **Idle Energy Rate (in kW):** The average rate of energy consumed [Btu/h (kJ/h) or kW] by the fryer while "holding" or "idling" the frying medium at the thermostat(s) set point.

The different sets of measured parameters reflect the different purposes of the three schemes:

- HKI data are focused on an objective method, reproducibility of the results and comparability of the appliances. In the deep fat fryer example, energy consumption for several processes (preheating, holding and frying) are recorded as well as the production volume per hour.

- ENAK data serves to calculate the close-to-real-life energy consumption for individual kitchens with their specific load profile and operating routines. Energy consumption for several processes are recorded.

- ENERGY STAR data serves to distinguish the models on the market with above-average energy efficiency. ENERGY STAR certified deep fat fryers must meet minimum cooking energy efficiency and idle energy rate requirements. According to their website, ENERGY STAR certified standard fryers "are about 30 percent more energy efficient than standard models and large vat commercial fryers (…) are nearly 35 percent more energy efficient than non-certified models." The recorded data focuses on key parameters that best reflect the energy efficiency of the appliance.

Energy performance data for deep fat fryers from HKI, ENAK and ENERGY STAR

The following Figures 2, 3 and 4 show graphs of the deep fat fryer data from the three schemes.

Figure 12. Graphs of the HKI data for “deep fat fryers” (multi-functional devices)

Energy consumption in kWh

(x-axis: Production volume per hour in kg/h)

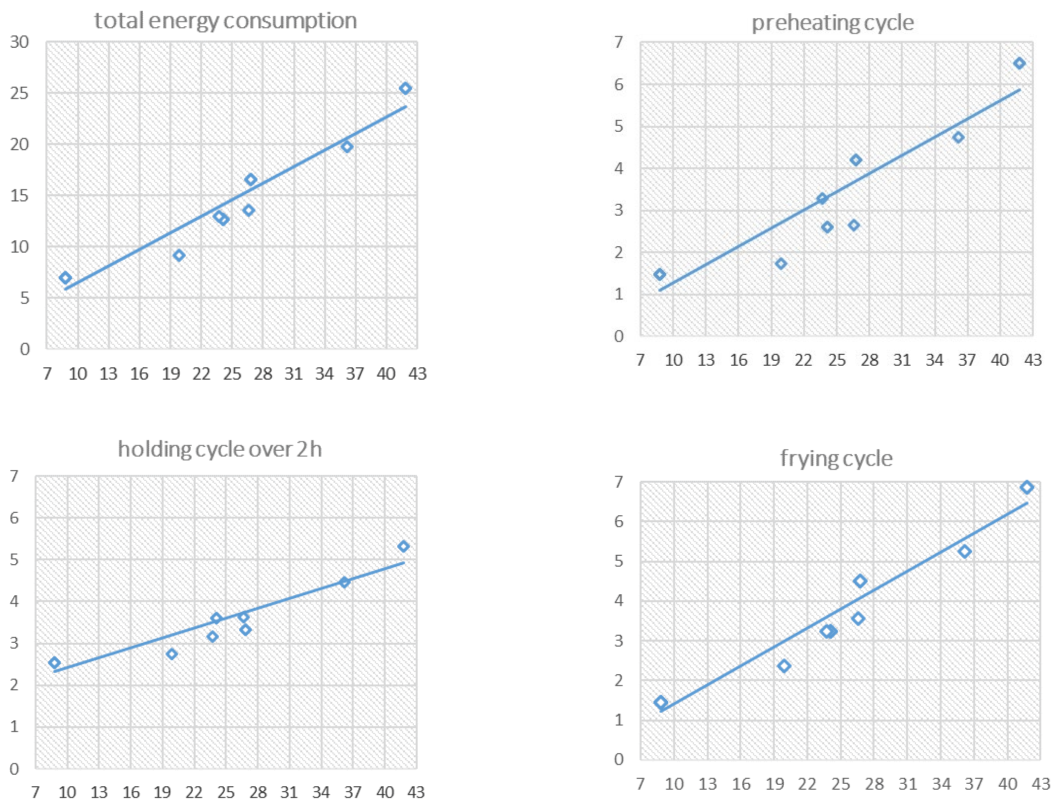


Figure 13. Graphs of the ENAK data for deep fat fryers

Energy consumption in kWh

(x-axis: Capacity in liters)

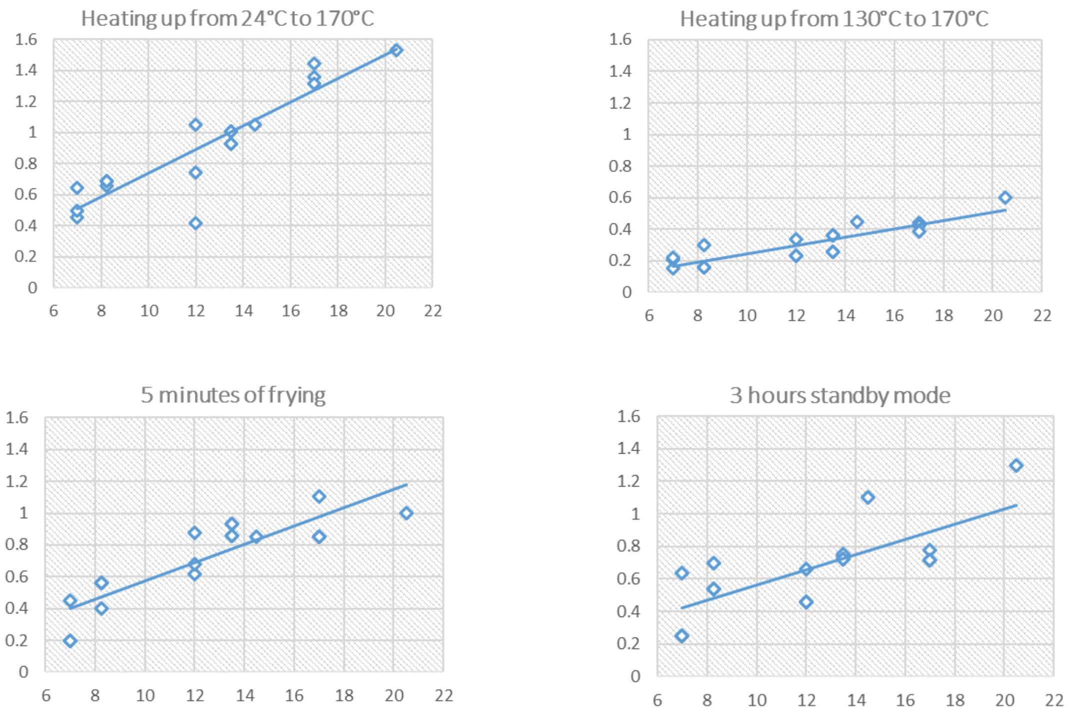
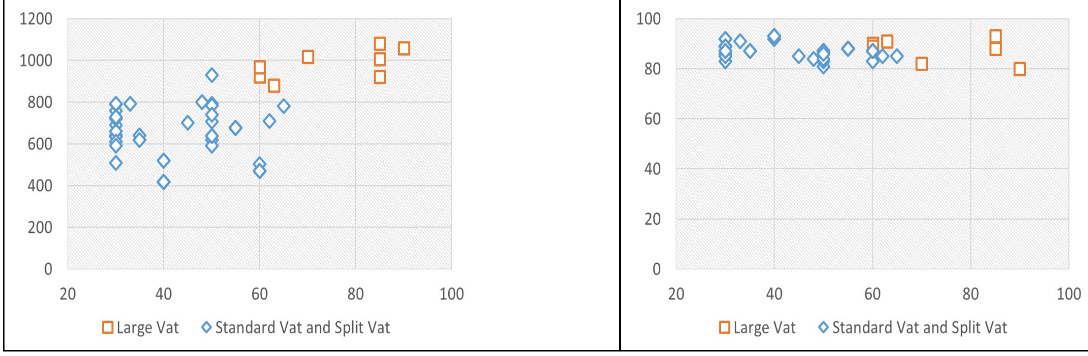


Figure 14. Graphs of the ENERGY STAR data for electric deep fat fryers

Idle Energy Rate in W	**Cooking Energy Efficiency in %**
(x-axis: Shortening Capacity in lbs)	(x-axis: Shortening Capacity in lbs)



The data sets are too different to compare. Even so, we can point out two insights that we found interesting.

In the ENAK graph for the process "heat up from 24°C to 170°C" the models for 12 liters stand out, as they show large differences in energy consumption between the models. Interestingly those three models are of the same brand. Looking into the technical data sheets of those models, it showed that the model with highest energy consumption claims a higher output per hour (kg fries per hour). However, this parameter is not considered in the ENAK database as it is difficult to measure and evaluate while still ensuring the same food quality according to ENAK.

The ENERGY STAR data shows differences in idle energy rate up to 35 percent for same size fryers type "standard vat and split vat". For "large vat" fryers, the difference is smaller with up to 15 percent. The cooking energy efficiency varies between 80 and 93 percent. For HKI and ENAK, we judge the data to be too sparse to derive anything like these conclusions.

Part 3 – Possible pragmatic approaches to ecodesign requirements?

In this chapter, we investigate the possibility of setting energy efficiency requirements based on technical features instead of measurements. Energy efficiency requirements usually depend on an energy measurement. Based on the measured energy consumption an energy efficiency index is calculated to assess a product's energy performance. However, energy measurements involve considerable effort. It could be pragmatic for both manufacturers and market surveillance authorities if energy efficiency requirements would simply involve the presence or absence of specified technical features. We probe this idea using the results of comparative measurements with and without insulation and lid carried out by the manufacturer MKN, HKI member, for the purpose of this paper. We also consider findings from a recent study by ENAK on the energy efficiency of 16 commercial kitchen appliances in Switzerland [4].

Then, we also explore how user behavior could be addressed by ecodesign requirements. Both HKI and ENAK emphasize that a major part of the saving potential lies with the kitchen staff, how they operate the equipment. We propose requirements for suppliers to provide information on efficient usage of equipment as well as requirements for smart controls that automatically promote efficient usage. As a result, we formulate a few requirements for discussion.

Comparative measurements with or without insulation and lid

Comparative measurements were carried out by the manufacturer MKN, who is a member of HKI, in order to test the effect of insulation and lid on energy use. A larger sized deep fat fryer (30 liters, 10 kW connected load) and a mid-sized cooking kettle (150 liters, 25 kW) were modified and measured with different levels of insulation. The insulation material used was glass wool with lamination, 20 mm thick, 0.035λ = R-value of 0.57 m^2*K/W. The measurements were done approximately according to the applicable DIN standard, with calibrated measuring instruments, in the MKN laboratory certified according to CTF, ISO17025, Stage 2, but ambient conditions were not strictly controlled.

Table 6. Measurement of a deep fat fryer, according to DIN 18873-3 (approx.)

Modification of the insulation	Measured energy consumption	
	Holding cycle for 1 hour	Frying cycle 2 kg raw mass
1. Measurement at 175°C, without insulation of the basin and with 20 mm insulation to the front panel	0.76 kWh	0.92 kWh
2. Measurement at 175°C, with insulation of the basin with R-value of 0.57 m^2*K/W	0.67 kWh	0.9 kWh
3. Measurement at 175°C, with insulation of the basin with R-value of 1.14 m^2*K/W (40 mm)	0.67 kWh	not measured
4. Measurement at 175°C, with insulation of the basin with R-value of 0.57 m^2*K/W and one-walled lid on the oil basin	0.4 kWh	not measured
5. Measurement at 120°C, with insulation of the basin with R-value of 0.57 m^2*K/W (Remark: For reheating to 175°C, 0.65 kWh is required and the cooling phase is 100 minutes)	0.37 kWh	not measured
6. Measurement at 120°C, with insulation of the basin with a R-value of 0.57 m^2*K/W and a one-walled lid on the oil basin	0.2 kWh	not measured

Table 7. Measurement of a cooking kettle, according to DIN 18873-15 (approx.)

Modification of the insulation	Measured energy consumption		
	Preheating cycle	Cooking cycle to 95°C cooking temperature	Holding cycle for 1 hour
1. Measurement without insulation of the basin and one-walled lid (150 liters of water, filled to nominal capacity)	not measured	7.63 kWh	1.87 kWh
2. Measurement without insulation of the basin and double-walled, insulated lid (150 liters)	12.9 kWh	not measured	1.16 kWh or 0.0077 kWh/liter
3. Measurement without insulation of the basin and double-walled, insulated lid (50 liters of water, 1/3 of nominal capacity)	not measured	not measured	1.09 kWh or 0.22 kWh/liter
4. Measurement with insulation with R-value of 0.57 m^2*K/W of the basin and double-walled, insulated lid (150 liters)	12.8 kWh	6.74 kWh	1.03 kWh
5. Measurement with insulation with R-value of 0.57 m^2*K/W of the basin and one-walled lid (150 liters)	not measured	6.89 kWh	not measured

Saving potentials

Double-walled, insulated lids have a notable energy advantage in cooking kettles: 38% less energy use in the holding cycle. Insulation with R-value of 0.57 m^2*K/W leads to 11% less energy use in the holding cycle for the cooking kettle. However, in the measurement of the preheating cycle, the effect of insulation is small with the cooking kettle: only 0.8% less energy use.

When we put the energy use of the preheating cycle in relation to the holding cycle, it becomes quite clear that the preheating cycle dominates: one heating cycle with the cooking kettle (12.9 kWh) corresponds to 11 hours of holding (11 h x 1.16 kWh/h = 12.76 kWh).

To estimate the overall energy-saving effect for deep fat fryers, we calculate two scenarios. The measured energy use for heating up was 2.0kWh (20.3 kg oil from 20°C to 175°C, insulated basin). Note that similar to the above relation with cooking kettles, also here one frying process (0.9 kWh) dominates and corresponds approximately to 1 hours of holding (0.8 kWh).

Scenario canteen: 2 hours production for the serving of 15 batches and 2.5 hours holding

- Without insulation: 22.65 kWh energy consumption
- With insulation: 21.94 kWh energy consumption → 3% less energy use

Scenario snack bar: 1 hour production for 10 batches and 9 hours holding

- Without insulation: 17.25 kWh
- With insulation: 16.24 kWh → 5.8% less energy use

Other conclusions

The measurements showed that the efficiency of electric fryers with heating elements in the oil reaches 85-90%, depending on which heat capacity for the oil is chosen. The energy needed to heat up 20.3 kg of oil from 20°C to 175°C was measured with 2.0 kWh for an insulated fryer basin and 2.1 kWh for an uninsulated fryer basin. The calculated energy needed to heat the oil is 1.66 kWh if the 1.9kJ/kgK standard heat capacity for oil is used.

The deep fat fryer was additionally measured with a double insulation with R-value of 1.14 m^2*K/W (40 mm). The energy used was the same as with single insulation with R-value of 10.57 m^2*K/W (20 mm). Conclusion: Insulation thickness greater than with R-value of 0.57 m^2*K/W does not bring any energetic improvement for deep fat fryers. The sweet spot may lay at a lower R-value, this has not been further investigated.

For cooking kettles with insulated lid, the measurements showed that the efficiency reaches 95%. To heat up 150 liters of water from 20°C to 90°C the cooking kettle used 12.8 kWh of energy when the kettle was insulated, and 12.9 kWh when the kettle was not insulated (both with insulated lid). The calculated energy demand is 12.2 kWh.

When the cooking kettle was operating in standby mode at 90°C with less than the nominal filling quantity of 150 liters, it became less efficient: with 150 liters, it used 0.0077 kWh per liter in one hour, whereas with 50 liters it used 0.022 kWh per liter in one hour. For kitchens with several cooking kettles, it is therefore recommended to have different sizes of kettles. This allows using them at nominal filling capacity as often as possible.

Findings from a study of 16 types of commercial kitchen appliances (ENAK 2021)

The aim of the study was to draw on the decades-long expertise of ENAK and its members in promoting energy efficiency in professional kitchens. Following a similar approach to EU preparatory studies for ecodesign, although on a smaller scale, the following 16 appliances were investigated:

- Cooking kettles
- Frying pans
- Pressure braising pans
- Combi steamers
- Bain-maries
- Heated display cabinets
- Blast chillers/shock freezers
- Hood dishwashers
- Basket transport dishwashers
- Conveyor belt dishwashers

- Salamanders
- Deep fat fryers
- Pasta cookers
- Stirring machines
- Mixers
- Slicing machine

Saving potentials

ENAK identified energy-saving measures for the 16 appliance types and quantified the potential savings. ENAK emphasizes that the calculated numbers are rough estimates that are subject to uncertainty. Important to bear in mind is also that the savings of separate measures for one type of appliance cannot simply be added up. The theoretical saving potential if all measures were implemented would be lower than the total sum.

For this paper, we rank the different measures based on their impact across all the studied appliances (see Figure 5). The three most important measures are better insulation of the appliances, regular training of the staff, and intelligent controls that avoid energy waste. The next three important measures revolve around hot water. ENAK has listed other measures whose savings effect is smaller and which will not all be discussed here.

Figure 15. Ranking of energy-saving measures for commercial kitchen equipment as identified by ENAK (values in GWh/year across the 16 studied appliances for annually sold units)

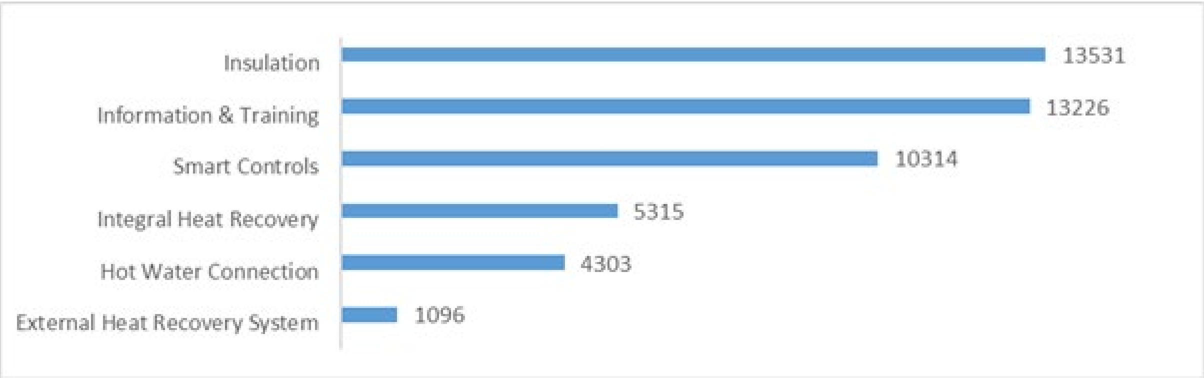


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Table 6 shows the saving potentials of the six most effective measures for each appliance type, as estimated by ENAK. The total values are the same values as in Figure 5.

Table 8. Saving potentials per appliance type for different measures in GWh/year for annually sold units in Switzerland (ENAK)

	Insulation	Information & Training	Smart Controls	Integral Heat Recovery	Hot Water Connection	External Heat Recovery
Cooking kettles	360	65	626	-	545	425
Frying pans	699	116	641	-	-	80
Pressure braising pans	617	287	788	-	-	591
Combi steamers	1643	3085	509	-	-	-
Bain-maries	2446	64	917	-	575	-
Heated display cabinets	553	2	13	-	5	-
Blast chillers/ shock freezers	-	45	341	-	-	-
Hood dishwashers	469	1487	630	2780	1577	-
Basket transport dishwashers	84	1155	414	1648	935	-
Conveyor belt dishwashers	46	622	223	887	508	-
Salamanders	-	3757	4666	-	-	-
Deep fat fryers	6243	2497	502	-	-	-
Pasta cookers	371	44	44	-	158	-
Stirring machines	-	-	-	-	-	-
Mixers	-	-	-	-	-	-
Slicing machines	-	-	-	-	-	-
Total	**13531**	**13226**	**10314**	**5315**	**4303**	**1096**

Insulation: ENAK sees the largest saving potential in better insulation of the appliances. Within the limits of the study, ENAK was not able to define a measurable parameter that could be used to assess the quality of the insulation. Further studies would be needed. For some appliances, ENAK points out specific features that distinguish models with good insulation. With cooking kettles and frying pans, ENAK recommends that the lid should be double-walled and insulated for instance. With combi steamers, in case a boiler is present it should be insulated, and the cooking chamber doors should consist of several panes of insulating glass. Likewise, the housing of hood-type dishwashers should be double-walled, and the hood and hot water boiler insulated. An added benefit of better insulation with dishwashers is noise reduction - they work more silently.

Information & Training: Equipment handling is one of the most important factors for energy efficiency according to ENAK. They recommend that trainings for new employees is carried out at least once a year and that kitchen managers attend regular energy-saving trainings. Further, the appliances should be labeled with the most important user instructions. ENAK gives the following example for frying pans: Marking the heating times for different fill quantities (e.g. in 10-litre increments) and pictograms on the appliance to close the lid. Sometimes clearer designations for buttons or displays could help the users to choose the appropriate and energy-efficient mode, as reported by ENAK for hot display cabinets for instance. In their report, ENAK describes for each appliance the most common mistakes that are encountered in kitchens and what would instead be the proper way to operate the appliance. Examples are given in the next chapter for kettles and pans. The above-average fluctuation in the gastronomy sector as well as inadequate staff instruction often lead to unnecessary energy consumption says ENAK. Individual companies can remedy this by developing training concepts. For instance training videos that specifically focus on energy efficiency could contribute to saving energy.

Smart Controls: In the case of salamanders, deep fat fryers and pasta cookers, ENAK describes a single specific function that leads to savings. For fryers and pasta cookers it is automatic temperature reduction after a period of inactivity (e.g. from 170°C to 130°C for fryers and from 99°C to 50°C for pasta cookers after 30 minutes of inactivity). According to ENAK one can frequently observe that the automatic temperature reduction is manually turned off in fryers and pasta cookers. This is probably an indication that users do not trust that the operating temperature can be reached again quickly enough. Marking the heating times on the appliances might help remedy this. For salamanders the energy-saving function is plate detection. The salamander is an open oven with strong top heat for gratinating and keeping food warm for short periods. To prevent the salamander from running continuously, some models have a plate detection system. The placing of a plate is detected and the heating is automatically switched on or off. The required operating temperature is reached again within seconds. The energy consumption is reduced by about 40% with plate detection according to ENAK's estimate. Other examples of smart controls that ENAK points out in their report for various appliances:

- Certain cooking processes could start only when the lid is closed.
- Alarm functions, e.g. when the lid is open too long or the appliance is in ready mode for too long.
- Integrated cooking programs (or scenes) can help the staff to operate the units efficiently. This can save both operating and labor times.

Integral Heat Recovery: Integral heat recovery applies only to dishwashers and brings large savings: 19% according to ENAK, for hood-type and conveyor-type dishwashers alike. The heat is recovered from the internal air of the machine or additionally from the dishwashing and rinse water. The inflowing cold water is preheated by a heat exchanger. For the air heat recovery, the accumulated steam is evacuated before the dishwasher opens, which also reduces the heat and humidity that escape into the room. An added benefit is a more pleasant indoor climate in the kitchen.

Hot Water Connection: Dishwashers and other equipment can be installed with a hot water connection to reduce their own electric energy use for heating water. This measure applies to all appliances that use a lot of hot water like cooking kettles, bain-maries, heated service counters and pasta cookers. Hot water connection does not work for dishwashers with integral heat recovery or integrated osmosis system (cold water connection required for technical reasons). The overall effect of this measure depends on the way the hot water is heated by the building services, if there are substantial heat losses in distributing the water, etc. There are also applications where the cooking process must necessarily begin in cold water, otherwise the product/food will be damaged.

External Heat Recovery System: In kitchens with large quantities of hot wastewater that is drained away, several appliances can be connected to an external heat recovery system. This system makes use of the fact that the wastewater must first pass through a grease separator. The grease separator can be upgraded with a wastewater heat recovery system.

Most common mistakes and best practices in equipment handling

ENAK describes good and bad practices that they often encounter in kitchens. This is done for each appliance in the study. Here is the example for commercial cooking kettles, frying pans and pressure braising pans:

1) Cooking and simmering with the lid open: It was found that often the lid is not put on when cooking, which leads to considerable heat loss.
2) Pan volumes are not used optimally: It was found that the appliances are often too large for the amount to be cooked, which means that more energy is used than necessary. The appliances are often oversized and not designed for the actual demand.
3) Appliances are switched on too early: Appliances are unnecessarily operated on standby.
4) Appliances are switched off too late: after cooking, appliances are often not switched off immediately.
5) Waste of hot water in repetitive batches: instead of continuing to use the hot water after boiling a batch, it is poured off and new cold water is boiled again, requiring more energy.
6) Misuse as hot water dispensers: hot water is incorrectly prepared and kept warm in the cooking pots for other activities.

7) In the case of pressure cooking, it was found that cooking is often done without pressure. The appliances can be used multifunctional, with the disadvantage that the efficient cooking option under pressure is not used enough.
8) It is also recommended to fill the cooking kettles with hot water already, if possible; this can save both time and energy for boiling.

Possible requirements: technical and information requirements

Technical requirements

Based on the comparative measurements, the ENAK study and additional considerations of HKI members, we propose the following technical features as possible requirement for new appliances:

1) Cooking kettles with double-walled, insulated lid and insulated basin with a thermal insulation of at least R-value 0.57 m^2*K/W

2) Tilting and standing frying pans with double-walled, insulated lid

3) Deep fat fryers with lid and insulated basin with a thermal insulation of at least R-value 0.57 m^2*K/W. Cold zones for extending the lifetime of the oil in deep fat fryer basins would not need insulation. Electronic fryers with automatic temperature reduction.

4) Dishwashers with integrated heat recovery

5) Salamanders that automatically switch on and off by means of plate detection

Further studies are certainly necessary to clarify details. Market shares and prices of these technical features have to be considered. The market share of deep fat fryers with automatic temperature reduction is probably only about 15% in Germany, since the cost for electronic fryers is much higher than for thermostatically controlled fryers.

Multi-functional devices would have to be treated separately. They do not clearly fall into one of the categories cooking kettle, frying pan or deep fat fryer.

Information requirements

The ENAK study illustrates good and bad practices for 16 appliances and highlights the importance of staff training and information for realizing large energy savings. Advice can also be found in the HKI guideline "Protecting the climate and reducing costs - A guide to Energy Efficiency in Commercial Kitchens" and other publications. So how can ecodesign requirements support staff training? The ecodesign regulation could demand of the suppliers to make necessary information available. It could be obligatory that user manuals have a dedicated chapter on energy efficient operation of the device. Further, suppliers could be obligated to provide information material for staff training on free accessible websites. This could either be branded material about their own products, or manufacturers could produce common material together for specific appliance types. Common material could be distributed on shared platforms provided by associations for example. Among other things, training videos and e-learnings might be especially useful. The industry cannot train every kitchen employee in person on a regular basis. Information material, videos and e-learnings can be used in a decentralized manner. The kitchen management can train employees when the time schedule within the company allows it. Coordination with manufacturers is not necessary. Each person would be free to acquire the knowledge individually.

Discussion

Energy data: No uniform methods and no comparable data basis

Our original idea of comparing energy consumption data between the three databases of HKI, ENAK and ENERGY STAR turned out to be rather frustrating. We knew that the measurement methods are different and that it would be mostly a matter of illustrating those differences. But it turned out, that even product categories of the three databases are rather different and the available data often contained only models from very few manufacturers, as a result the data could not really be compared.

Opportunities and limits for ecodesign and energy labelling regulation

Commercial kitchen appliances offer significant saving potentials. According to the savings estimated by ENAK, the most effective measures are introducing modern equipment technology with good insulation and sophisticated controls, as well as regularly training kitchen staff. Can these potentials be realized with a simplified approach through ecodesign requirements as we investigate in this paper? With regard to information material for staff training, we see an important opportunity for ecodesign regulation. The idea of the simplified approach to technical requirements based on specific features instead of energy measurements is not yet entirely convincing after the comparative measurements presented in this paper. There could be significant opportunity in the case of dishwashers and salamanders, where the energy-saving feature is integral heat recovery or automatic control via plate detection, respectively. However, it seems more difficult to capture large savings when the requirement concerns insulation as in the examples of cooking kettles and deep fat fryers.

Given the complex range of equipment and applications as well as the sparse data on energy consumption, it is conceivable that the European Commission will find an energy label not practical for commercial kitchen appliances. All the more reason to study in greater depth which effective and feasible measures can be implemented through ecodesign regulation.

To close, we would like to point to complementary measures that are beyond the possibilities of ecodesign and energy labelling regulations.

Since ecodesign regulations only affect the newly sold appliances, it takes many years for a modern generation of models to permeate the appliance stock in any significant way. In order to accelerate the introduction of modern technologies, it would be helpful to have wide and easy-to-apply-to financial support for the replacement of old appliances. In particular, appliances that are 15 or 20 years old and older should be replaced from an energy perspective.

Another problem is that the majority of kitchen operators do not know the energy consumption of the kitchen. Very few commercial kitchens have their own electricity meter. It would make sense to install a separate electricity meter in new buildings or when a kitchen is renovated. Separate electricity meters for the different areas dishwashing, cooking, refrigeration, ventilation and others would be even better. The gained transparency would increase awareness among operators and enable monitoring of measures like staff training or new equipment.

References

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[8] COMMISSION DELEGATED REGULATION (EU) 2015/1094 of 5 May 2015 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of professional refrigerated storage cabinets

[9] COMMISSION REGULATION (EU) 2015/1095 of 5 May 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers

[10] COMMISSION DELEGATED REGULATION (EU) 2019/2018 of 11 March 2019 supplementing Regulation (EU) 2017/1369 of the European Parliament and of the Council with regard to energy labelling of refrigerating appliances with a direct sales function

[11] COMMISSION REGULATION (EU) 2019/2024 of 1 October 2019 laying down ecodesign requirements for refrigerating appliances with a direct sales function pursuant to Directive 2009/125/EC of the European Parliament and of the Council

[12] https://ecoprorefrigeration.eu/index.html/ - website dedicated to the review study ecodesign & EU energy label of professional refrigeration products

3 MARKET SURVEILLANCE AND TESTING

When less is more: How technology can streamline and scale up the MVE process. The EEPLIANT3 'CybPort' tool for data collection and mass data migration of product cases to European Commission's ICSMS

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Abstract[154]

ICSMS (Information and Communication System for Market Surveillance) is the internet-based platform managed by the European Commission (DG GROW) in which Market Surveillance Authorities (MSAs) across Europe can share information about the enforcement of European internal market legislation on non-food products. It plays a crucial role by allowing national authorities to communicate the result of their investigations across borders, leading to a more efficient enforcement and use of resources.

However, the task of recording inspection cases into this database has its own limitations, as it requires individual encoding of data for each single case in multiple input fields relevant to the compliance of products to the respective legislation.

To unburden the recording and transfer of data from MSAs to ICSMS, the EU-funded Energy Efficiency Compliant Product 2 Joint Action - EEPLIANT2, relevant to the Energy Labelling and Ecodesign legislations, developed a technology-based tool that allows the bulk semi-automatic upload of cases directly to ICSMS. The result is cost and time efficiencies for market surveillance. It works by gathering all requested data in an external database (resembling a spreadsheet MS Excel-like environment) and creating a link with the ICSMS' API for a semi-automatic upload of the selected cases.

This tool is being further developed under the EEPLIANT3 Concerted Action. In the long term, the ambition is to expand its utility beyond project-specific uploads across all harmonised product sectors.

Introduction

Keeping non-compliant and unsafe non-food consumer products from the European Union (EU) market is the role and function of monitoring, verification, and enforcement (MVE) schemes and market surveillance in Europe as entrenched in Regulation (EU) 2019/1020. Its legal requirements apply to 70 harmonised product-related legislations. The goal is to protect public interests concerning the health and safety of citizens, competitiveness, and the environment[155].

It is because of market surveillance and the enforcement of these requirements that every year thousands of products are banned, recalled or withdrawn, or are subject to corrective measures to achieve compliance. Cross-sectorial data between 2005 and 2019 show a total of 24,769 notifications for dangerous non-food harmonised and non-harmonised products[156] in the European Commission's (EC) Safety Gate rapid alert system[157]. When disaggregating, one observes that the annual number of Article 12 notifications for products presenting a serious risk to consumers/end-user has been crossing the 1,500 mark steadily from 2011 onwards[158]. In terms of costs, the damage to EU consumers and society due to accidents caused by unsafe products is estimated at EUR 11.5 billion per year[159].

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[154] I would like to thank Torben Rahbek, senior market surveillance expert and technical facilitator in the EEPLIANT3 Concerted Action, for his invaluable comments on the first draft of this paper.

[155] Regulation (EU) 2019/1020 of the European Parliament and of the Council of 20 June 2019 on market surveillance and compliance of products and amending Directive 2004/42/EC and Regulations (EC) No 765/2008 and (EU) No 305/2011 (OJ L 169, 25/6/2019).

[156] Non-harmonised products fall under the General Product Safety Directive (GPSD). GPSD applies to consumer products when there are no other specific provisions in Union legislation for the safety of the products concerned, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32001L0095 (accessed 10 Jan 2022).

[157] The Safety Gate web portal, at https://ec.europa.eu/safety-gate/#/screen/pages/reports (accessed 10 Jan 2022).

[158] European Commission (2021), Study to support the preparation of an evaluation of the General Product Safety Directive as well as of an impact assessment on its potential revision, Part 1

[159] Ibid.

As ever, compliance with EU product-related policies by economic operators is downright pivotal to improve consumers' confidence, long-term investment for research and (viable) innovation (more on that later), and fair competition. But also to mitigate climate change. Energy efficiency holds a large share in all EU energy transition and decarbonisation scenarios by 2050. Ecodesign and Energy Labelling policies for energy-efficient products are estimated to contribute to almost half of the EU aggregate 2020 energy saving targets[160]. At least 10% of contingent energy savings over time is lost due to cross-sectoral product non-compliance[161]. That is, 153 TWh/a loss of primary energy and 27 MtCO2eq/a of additional GHG emissions in 2030 (against the baseline/business as usual scenario)[162].

To produce results, policies need to be enforced consistently. Market surveillance is the subsidiarity-based[163] responsibility of the Member States and their designated market surveillance or other enforcement authorities[164] in charge of controls on non-food products entering the EU market.

However, no prescription is given on how Member States should implement and enforce the market surveillance legislation. Despite the ambition to maximise harmonisation, it is important to recognise that no one-size-fits-all operational model exists or could exist, independent of cultural, political, financial and legal variation. The flaws of this landscape are well-captured in several EC evaluation studies. The fragmentation of market surveillance structures, with centralised and decentralised modes at sectoral and/or regional level, the finite resources, often reflecting a lack of political incentive and buy-in awash in nebulous return-on-investment narratives and flimsy public pressure, regardless of the evidence[165], and asymmetric information induce an impaired and unequal implementation of Union legislation across the EU and across product sectors[166]. Looking under the hood, data show that EU-wide market surveillance costs on average only a few euros per thousand inhabitants. That means 0 to maximum 0.5 inspectors per million inhabitants on average, with budget and staff concentration in a small number of Member States[167].

To make things worse, the sheer volume of products sold online with the irreversible rise of e-commerce and digitalisation (e.g., Internet of Things and connected devices) over the past decade amplifies the problem. Today, e-commerce makes conservatively 10-15% of total retail sales in the EU[168] and despite the sharp decline of online sales in the tourism and services sectors amid the Covid-19 health crisis. In 2020, 73% of internet users in the EU shopped online according to Eurostat[169]. B2C trade in goods is estimated at EUR 312 billion in 2019. The share of online sales in total retail (excluding tourism, automobile, gas, and tickets) for the same year is on average 10.1% (this is the mean of 11 selected EU countries)[170]. This adds jurisdictional and traceability[171] constraints to MSAs specifically concerning B2C transactions and imports of products from third countries (extra EU imports), estimated in 2015 to over 30% of the trade volume of harmonised products[172].

But regardless of all gaps and inefficiencies, the footprint and the effectiveness of EU market surveillance are somewhat staggering. Data from 15 Member States for the period 2010-13 indicate that on average each

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[160] European Parliament (2017), The Ecodesign Directive (2009/125/EC). European Implementation Assessment; European Commission (COM(2016) 773 final), Ecodesign Working Plan 2016-2019; European Commission (2021), Ecodesign Impact Accounting Annual Report 2020.

[161] A flat estimate across time and for all product groups, computed by the European Commission and European Court of Auditors, European Court of Auditors (2020), EU action on Ecodesign and Energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance, Special Report.

[162] European Commission (2021), Impact Accounting

[163] In the context of the EU, especially post Maastricht, the principle of subsidiarity is one of the core organising principles of the EU law. It serves to regulate the exercise of the Union's non-exclusive competence/powers. Put simply, it determines the circumstances in which action should be taken at European, rather than at national level, 'by reason of the scale and effects of the proposed action', European Parliament (2021), Fact Sheets on the European Union 2021.

[164] Typically, in cooperation with customs authorities.

[165] PROSAFE (2010), Best Practice Techniques in Market Surveillance, especially p. 16 and 31, at https://prosafe.org/images/Documents/EMARS/EMARS_Book_of_Best_Practice.pdf (accessed 23 April 2022).

[166] European Commission (2017), Ex-post evaluation of the application of the market surveillance provisions of Regulation (EC) No 765/2008; European Commission, SWD(2017) 469 final, REFIT Evaluation; European Commission (2021), Evaluation of the General Product Safety Directive; European Commission, SWD(2017)466, Impact Assessment.

[167] Excluding medical devices, cosmetics and toys sectors; European Commission, SWD(2017) 469 final, REFIT Evaluation

[168] Ecommerce Europe and EuroCommerce (2021), 2021 European E-commerce Report

[169] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=E-commerce_statistics_for_individuals (accessed 11 Jan 2022)

[170] European Commission (2021), Evaluation of the General Product Safety Directive; https://www.retailresearch.org/online-retail.html (accessed 11 Jan 2022)

[171] Traceability is the ability to identify, track and trace a product and its components along the supply chain (manufacturers, importers, distributors, online marketplaces, information society service provider, etc.).

[172] European Commission, SWD(2017)466, Impact Assessment

country performs 7,493 product inspections (combined for harmonised and non-harmonised sectors) per year[173]. A recent study, with mixed 2018 and 2019 country data, estimates the annual total number of inspected consumer products in the EU at 114,112[174]. Again based on mixed 2018-19 data, the total number of product recalls (voluntary and mandatory combined) in the EU can reach 2,600 in a year, a clear underestimation considering the recorded data limitations[175].

Still though, less than 1% of the European market is verified via laboratory testing against the minimum ecodesign performance requirements[176].

And because of data and other methodological limitations, such as the most common hand-picked/risk-based product sampling strategies within the "high probability of non-compliance" market segment, measuring the 'real' levels of non-compliance across all sectors and for each product group is a rather tricky business. That said, all proxies (e.g. Safety Gate/RAPEX alerts) and trajectory data from national or joint inspections since 2010 concur: for all sectors and product groups with available data, the rates of non-compliance seem to be consistent and relatively high on average. For example, a cross-country analysis of 2010-13 inspection data shows a 42.2% median level of non-compliance for toys, construction products, low voltage electrical products, electromagnetic and radio equipment, and personal protective equipment[177]. Similarly, most joint campaigns, including those funded by the European Commission, report non-compliance rates often over 20%[178].

Clearly, not all product compliance and safety problems in the Single Market can be solved by market surveillance. Starting from the premise that a 100% compliance rate in the market is unrealistic, and acknowledging the heterogeneity of gaps and inefficiencies between Member States and across product sectors, the question to answer is what are the shortcuts to scale up market surveillance solutions for the long term? How can resources be directed to activities that leverage knowledge and technology spill-overs and incentivise economies of scale? And how can we achieve more with less?

In this paper, we argue that the next big thing in market surveillance, and one of the few solutions ticking most of the boxes, is digital transformation and big data. Put simply, new technologies and automation in the service of market surveillance. Here, we focus on Information and Communication Technology (ICT) systems. And more specifically on an EU-funded cloud-based software application for the semi-automatic bulk register of inspection data in the Information and Communication System for Market Surveillance (ICSMS), the main internet-based database and communication platform on non-compliant products for EU MSAs[179].

Technology, data, and market surveillance

Digitalisation is a process, not an event. In recent years, various technologies have been deployed to support market surveillance across the EU. The most common are Web Application programming interfaces (APIs), cloud computing, machine learning, and Artificial Intelligence (AI). Their implementation in market surveillance tools is wide. For example, the 'NordCrawl' project under the Nordic Council of Ministers[180], the 'Energy Labelling Surveillance (ELS)' case management system used by the Sustainable Energy Authority of Ireland (SEAI) for in-store and online labelling checks, Tukes' Nettidogi 'webdog' and eSurveillance ecosystem[181], 'Holmes' database and the Generic Inspection App GIA)) for mobile devices both developed by the Human

[173] European Commission (2017), Ex-post evaluation

[174] European Commission (2021), Evaluation of the General Product Safety Directive

[175] One of the biggest, if not the biggest, barrier to an integrated analysis of EU market surveillance and cross-sectoral measurement of non-compliance to date is a lack of homogeneity and consequently the data gaps in national reports on market surveillance activities.

[176] Alun Lewis Jones (2017), Is it time for a European market surveillance coordination body? Redefining monitoring, verification, and enforcement of European product policy, ECEEE 2017 Summer Study Proceedings

[177] Again, it is important to remember that, for the most part, all these numbers reflect a risk-based sampling approach. European Commission, SWD(2017)466, Impact Assessment

[178] European Commission (2021), Evaluation of the General Product Safety Directive; also see reports of EU (co-)funded Joint Actions on product safety and energy efficient products, coordinated by PROSAFE since 2006, at www.prosafe.org and www.eepliant.eu. It is important to not that the results of these actions represent the targeted efforts of the participating authorities to identify unsafe and non-compliant products, and therefore they do not provide a statistically valid picture of the market.

[179] https://webgate.ec.europa.eu/icsms/?locale=nl (accessed 13 Jan 2022)

[180] Bennich, Stengard, Christensen, Hartikainen, Mogensen, and Larsen (2017), Using webcrawler techniques for improved market surveillance - new possibilities for compliance and energy policy, ECEEE 2017 Summer Study Proceedings

[181] https://marek.tukes.fi/; https://slideplayer.fi/slide/17119761/ (accessed 13 Jan 2022)

Environment and Transport Inspectorate (ILT) in the Netherlands[182], the 'AIME' AI image recognition software for e-commerce market surveillance of the Danish Safety Technology Authority (DSTA)[183], or BAM's Energy Label WebCrawler are all seen as efficiency-driven solutions that help MSAs improve decision-making in relation to sampling strategies (bending more random with non-random approaches), increase the coverage and representativeness of the market, and at same time reduce costs.

However, even though cross-country analyses of ICT employment and adoption of new technologies are rather limited to date, available evidence suggest considerable variability and heterogeneity among MSAs in this respect[184].

Regardless of their function, what all these digital tools share is the ability to collect, process, and exchange large volume of publicly available data and information[185], in real time, from various web sources. Data can reshape how we think about market surveillance. In its classical form, risk-based market surveillance on highly suspicious product sectors has been the dominant practice, driven by the large number[186] and geographical spread of ill-equipped MSAs and the size of the EU market. As we saw, for the MSAs, this implies prioritising these sectors and products that seemingly present a high probability of non-compliance. Priority-setting criteria may include the results of prior MVE campaigns, product sales, price and distribution channels, the origin of the product, consumer complaints, accident data, new technologies, etc. In the past, these were grounded in little, scattered, and often outdated or even anecdotal evidence[187].

There is a correlation between data analytics and MVE impact. The more data the MSAs have across the EU market, the better the fitness of their sampling strategy and its optimal mix (statistically random/hand-picked). Market intelligence enables MSAs not only to avoid a duplication of efforts, but also to target the right product groups within sectors and combine this, for example, with clusters of economic operators across the supply chain with a bad track record of non-compliance. Knowing which products have already been found non-compliant provides good indications on what needs to be prioritised and sampled, and what specific models to avoid because they have already been controlled[188].

What seems to be a small improvement in efficiency leads to significant operating cost savings for the MSAs, and a more harmonised MVE across the EU. And this is why a cost-efficient exchange of information and communication on non-compliant products is important[189]. One example of ICT-enabled innovation is the EU-funded EEPLIANT case management digital application for the mass upload of product inspection and test data to ICSMS — the CybPort web application.

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[182] https://docplayer.nl/6521989-Holmes-het-inspectie-ondersteunende-systeem-van-de-vrom-inspectie.html (accessed 13 Jan 2022)

[183] https://www.kmd.net/press/press-releases/kmds-image-recognition-technology (accessed 13 Jan 2022)

[184] Again, the reasons for this are many and different among EU MSAs, ranging from budget and staffing limitations to a lack of knowledge and technical expertise and aversion to technology (that itself may be caused because of various socio-psychological, context-dependent, factors and stimuli).

[185] Though used interchangeably, the concept of "data" refers to a lower abstract or class of raw facts and figures. Conversely, "information" is commonly understood as the processed outcome of data, see Wersig, G. & Neveling, U. (1975), Terminology of documentation: A selection of 1200 basic terms. Paris: The UNESCO Press.

[186] The full list of national market surveillance authorities in Europe is published in 271 pages…

[187] As noted in various reports on market surveillance activities published by MSAs/Member States, and reports from EU-funded joint market surveillance actions, see https://www.prosafe.org/index.php/en/e-library/reports (accessed 22 Apr 2022) .

[188] European Commission/JRC (2020), Good Practices, p. 11 (Figure 1)

[189] European Commission (2017), Ex-post evaluation, particularly p. 66, 85, and 110; European Commission/JRC (2020), Good Practices, p. 20.

The EEPLIANT 'CybPort' web application

Before explaining what the EEPLIANT tool is all about, we should first discuss ICSMS, and its interface with the tool.

ICSMS is the EU's flagship database and data analytics platform for market surveillance. It allows MSAs and customs to store and exchange with one another information on non-compliant or dubious products. This includes inspection and test results, product identification data, accident information, information on measures taken against economic operators, etc.[190] The database is split between DRPI (Directive Related Product Information) fields that gather data according to the specificities of different products and legislations. Here are some examples of ICSMS data fields:

Table 9: Example of data fields in ICSMS

ICSMS Field ID	ICSMS Field Name	Required	Permissible values/remarks
GEN 2	Status	Yes	– Draft – Completed – Possibility for an appeal exists Subject of an appeal – On Hold / Paused – Investigation Started
GEN 7	Processing Member State	Yes	Name of the Member State in English
GEN 10	Date of Creation	Yes	The value has to be a date in the format DD-MM-YYYY
GEN 20	Distributor(s)	No	Address information (free text)

Once rendered, indexed data can then be searched, viewed, visualised in charts, tables, histograms or maps, and analysed. But, while all actors recognise and embrace the benefits of ICSMS, currently its application leaves much to be desired. As the European Commission's Joint Research Centre (JRC) puts it,

> *"[o]ne of the main issues of large databases such as ICSMS is the inhomogeneity of the data collected by different authorities, inspectors and officials. The system allows a great deal of freedom in the possibility to input information, causing the generation of duplications and miscategorisation."*[191]

To gain perspective, typically, during inspections, market surveillance officers were collecting and recording data with pen and paper, in different formats and nomenclatures. These data were then plugged into the various MSA databases manually. And from there, again manually, to ICSMS for EU-wide dissemination, in line with the provisions of Regulation (EU) 2019/1020. Little, if any, of this data has subsequently been routinely shared with other MSAs. Not surprisingly, the resources required for this task—revisit the inspection figures above to reckon the scale—make, for the majority of MSAs, its execution somewhat untenable.

Naturally, disparity in data collection, classification, and data quality was, first, compromising the aggregation and the statistical analysis of longitudinal geospatial data, and second, was plummeting the exchange of commensurable error-free information, and tapering the collaboration between MSAs. Most importantly, many MSAs sidestep ICSMS and do not record any information.[192] There are simply never enough resources to meet all needs. And when faced with finite resources, MSAs simply have to make choices and trade-offs even between hardcore tasks[193].

In 2016, the MSTyr15 (Market Surveillance Action for Tyres 2015) Joint Action (2016-2018) for checking the energy performance of class C1 summer passenger car tyres came to provide a newfound alternative to the traditional approach. A bi-directional (i.e., with an import-export function) cloud-based case management ICT

[190] https://webgate.ec.europa.eu/icsms/?locale=nl (accessed 13 Jan 2022)
[191] European Commission/JRC (2020), Good Practices, p. 20
[192] European Commission (2017), Ex-post evaluation
[193] Opportunity cost is an unescapable dimension that should always be considered.

programme, through which MSA users could upload, share and download information and documentation about on-site tyre inspections in real-time, which then are migrated to ICSMS at scale, in one sweep.

The implications are clear. The system streamlines data recording, and unburdens the data migration from MSAs to ICSMS. This prevents duplication of effort caused by the encoding of inspection data in two separate disconnected logs (first, in a national/regional one and then in ICSMS), and saves MSA resources that now can be diverted into MVE field work.

The first pilot iteration was a nexus of four modules (see Figure 2).

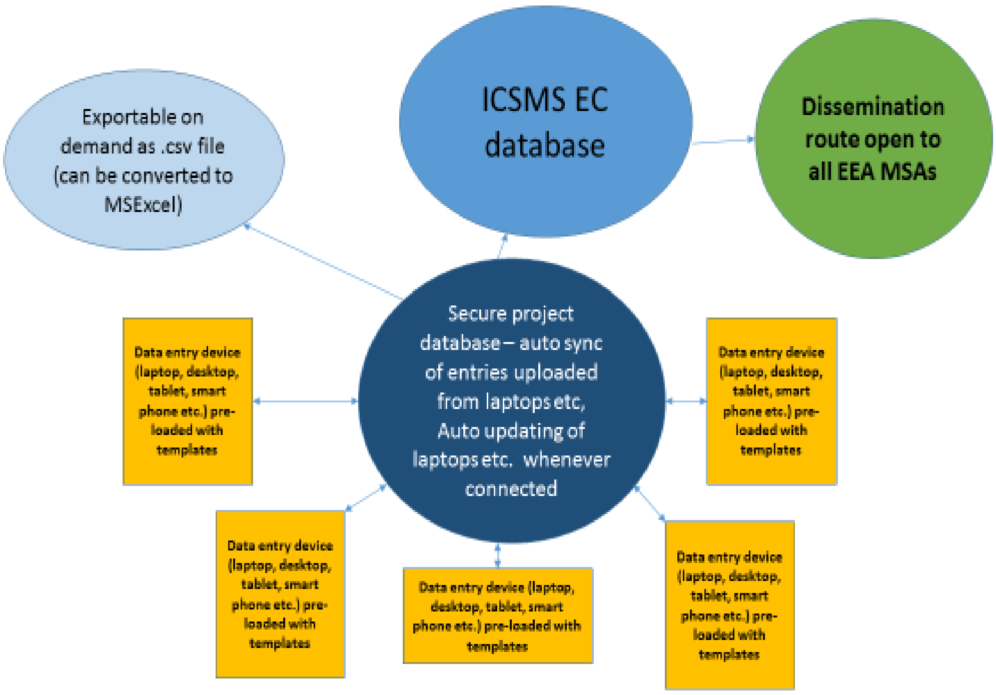
- An Android mobile application for tablet PCs to record (both in online and offline modes) and temporarily store inspection and test data (including photos of the physical samples examined). Data are first saved locally.

- A desktop web interface to the database. This can be accessed via a web browser. Users can enter data the same way as entered via the tablets or they can download data for further analysis and local storage.

- An SQLite3 Python database, auto-synchronised with the mobile and desktop applications. The database stored the data in a format compatible with ICSMS.

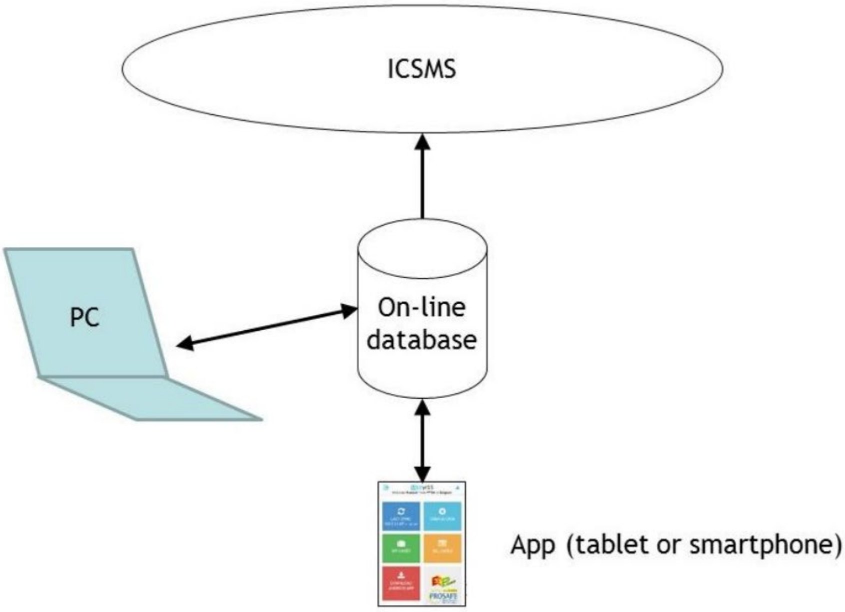
- A Windows client (native application) for the transmission of data from the CybPort database to ICSMS. The Windows Client connects with this database's API and, with said orientations for instruction, uploads the collected, by CybPort, data to ICSMS[194].

Figure 1. The ICSMS-CybPort concept (source: MSTyr15 Final Report, 2018)



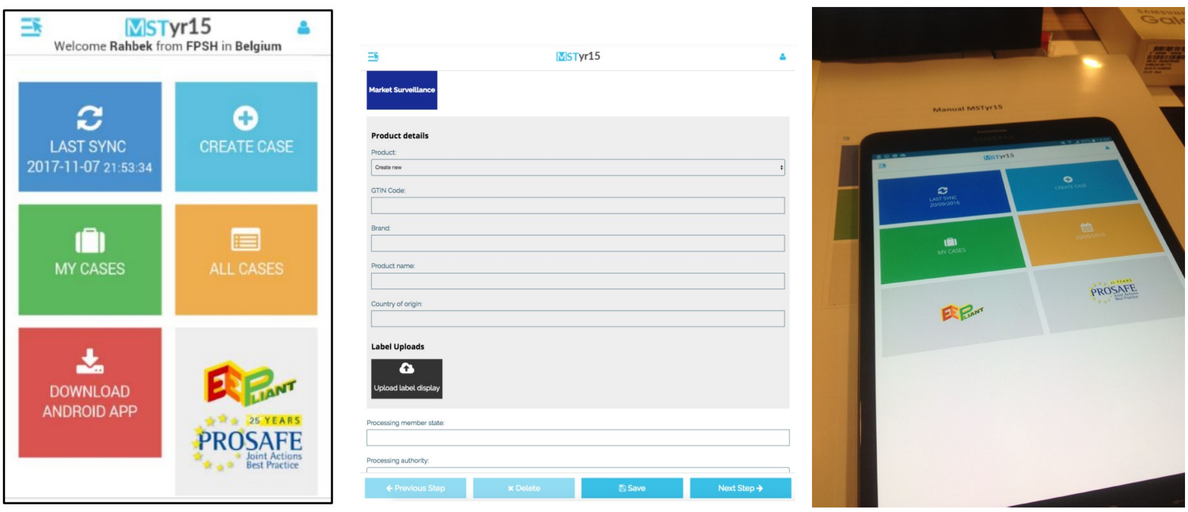
[194] For example, it takes a data point from the 'ECO21' column and uploads it to ICSMS under the corresponding 'ECO21' field.

Figure 16. Build of the first CybPort 1.0 iteration under MSTyr15



The system was beta-tested with data from MSTyr15. Over 12,000 label inspections of tyres were recorded in ICSMS because of the MSTyr15 CybPort 1.0 pilot.

Figure 17. User interface of the MSTyr15 CybPort 1.0 mobile app (examples), and its real-life display on a tablet



CybPort 1.0 was taken over by the successor EEPLIANT2 Joint Action on energy efficient products (2017-2020) to update and expand its import-export feature-set to more product categories (those targeted by the EEPLIANT2 inspection and testing activities). The EEPLIANT CybPort 2.0 was this time optimised exclusively for

use on PCs. Currently, EEPLIANT CybPort 2.1 iteration is part of the EEPLIANT3's portfolio of digital tools for ecodesign and energy labelling market surveillance[195].

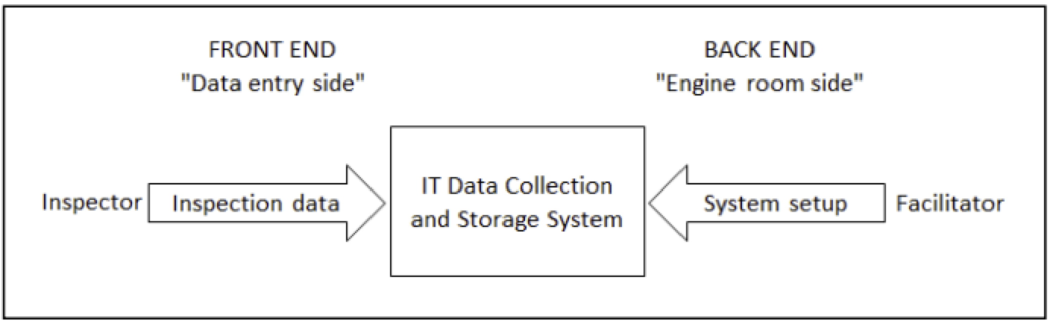
How EEPLIANT CybPort works

The web app is a spreadsheet-like interface used to record product inspection and test data in a secure cloud database. Data are then processed with Microsoft Excel-like formulas and functions, and consolidated into a single Workbook (i.e., a file that contains one or more Worksheets, a page with a collection of fields for encoding data, formulas, etc.) with all datasets to be uploaded and exported in a local environment.

The system has a front- and a back-end split architecture. The front-end is accessed by the inspector from any desktop web browser, and resembles a simple spreadsheet with rows and columns. The user enters inspection and test data here – one row for each product/unit. When the user completes the registration of a dataset, the information is then automatically uploaded to the online database. In the back-end of the application, imported data are being verified, cleaned, and normalised before upload to ICSMS. And finally, this is where the Worksheets can be modified and adapted to the specific requirements of any product category linked to the generic ICSMS DRPI, or to the just released energy-related DRPI, tailored for energy products under the Ecodesign Directive and the Energy Labelling Regulation.

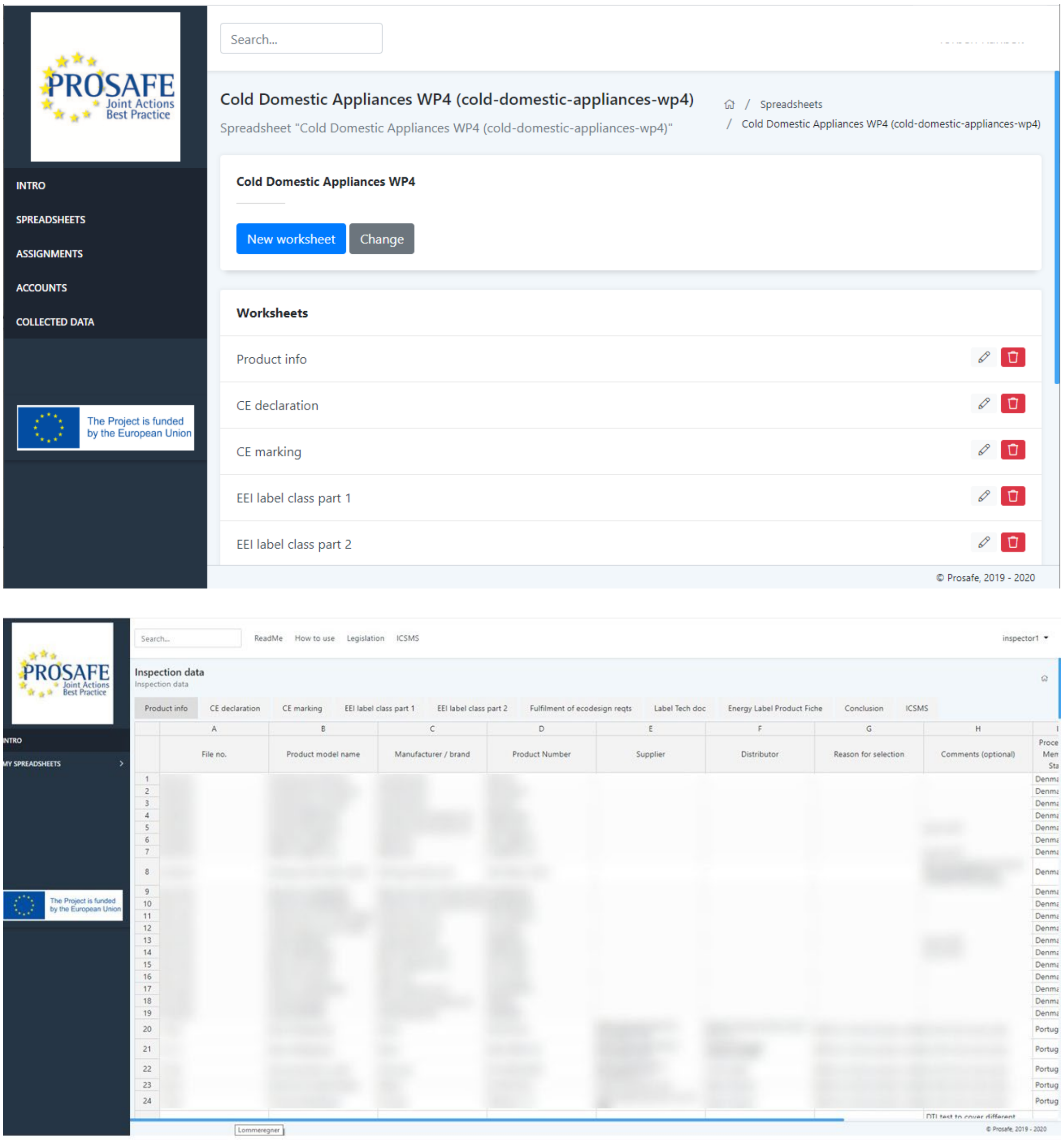
The key is to ensure that all the recorded data share the exact formatting requested by the ICSMS data fields. Since all data are processed in a central database, errors or voids are automatically flagged, and, where possible, autocorrected. A number of formula-based automations and drop-down lists support this process, for example, for entries with common data for certain parameters.

Figure 18. The set-up of the EEPLIANT CybPort 2.0



[195] This includes, a) the third iteration of the ICSMS-CybPort system, b) a WebCrawler, c) a new AI/Robotics tool, and d) a cluster of commercial or custom-made simple software solutions, adaptable to ecodesign and energy labelling MVE, https://eepliant.eu/index.php/horizontal-themes/it-tools (accessed 13 Jan 2022).

Figure 19. CybPort 2.0 web app interface - examples linked to EEPLIANT2 Work Package on household refrigerating appliances (confidential product-related data blurred)



What sort of data are collected?

In short, measured conformity-related values and qualitative attributes or properties for each model unit inspected by an MSA. Each data point corresponds to a specific field/entry in the CybPort database, which, as we saw, is a copycat of the ICSMS DRPI fields. Depending on the product and the applicable legislation and standards, these can include the ID of the sampled unit with details across the supply chain, pass/fail parameters, any observed deviations from checks on the technical documentation, labels and marking, also for those performed online on e-shops, and laboratory tests. Also, information is collected on the perceived risk class and the corrective measures taken against a non-compliant product with their justification, or voluntary actions by economic operators to bring a product into compliance.

For MVE on ecodesign and energy labelling such as the current EEPLIANT3 Concerted Action, data from laboratory checks concern the verification of energy performance in line with the Minimum Energy

Performance Standards (MEPS); for example, the declared by the producer Energy Efficiency Index (EEI) and Energy Efficiency Class *versus* the actual measured value after testing.

Little cost for big benefits

EEPLIANT CybPort comes to provide a sort of a hands-off solution to a problem with considerable implications for EU market surveillance. That was the conclusion of a needs analysis before deciding to invest EU resources in the development of the tool. Unnecessary resources were wasted in the collection and transmission of product compliance information between MSAs, resources that could have been directed elsewhere, or worse, not used whatsoever because of a mismatch in what the MVE ambition is and what the MSA can realistically deliver, and the need to rank order interventions.

But how does this very problem compare to other, perhaps more complicated and of a larger scale, problems in EU market surveillance? And as it is impossible to solve all market surveillance challenges at once constrained by limited resources, is investment in what might seem to be, for an outsider, a low-hanging fruit the right thing to do *at present*?

In short, yes. Of course, putting a value behind the costs and benefits of this tool (and factoring in the opportunity cost) would require a cost-benefit analysis (or similar), which has never been part of any of the three EU-funded projects occupied with the development of CybPort. For all the methodological imperfections of an assessment that relies heavily on empirical facts, the implementation of this particular tool has clearly created significant efficiencies, positive cumulative effects, and economies of scale for the MSAs involved in these projects. The amount of inspection data produced in Europe annually and the aggregate effort for each MSA and fatigue with the processing and registering of these data in Member State systems and ICSMS, one at a time, are two basal variables consistent over time, that show why investing a relatively small amount of money over time for the development and maintenance of the EEPLIANT CybPort tool is economically, operationally, and also environmentally—since MVE on energy products seems to be responsive to operational efficiencies —a good value for money.[196]

So what happens next? The question of sustainability

Long-term viability. That has been always one of the most complicated questions for new technologies with low monetisation potential—by default, because of the target market and its segmentation, i.e. unequal public market surveillance authorities—built in the context of an EU project with a fixed-term funding line[197].

Sustainable innovation requires long-term R&D investment. To stay functional, ICT tools need to be hosted, maintained, and updated continuously. Besides upfront costs for development, this implies provisions for dynamic adaption and maintenance costs. Similarly, scaling up EEPLIANT CybPort to cover more product groups and thus rendering a higher spill-over effect across sector, while keeping it responsive to future updates of ICSMS, would require a funding stream beyond the EEPLIANT3 implementation.

In EU market surveillance, by far the most common model used to sustain cumulative innovation and knowledge stock was the baton-passing from one EU-funded project to another. Despite its success, it comes to provide a temporary solution for a recurring need. For this reason, there is considerable uncertainty in the ability of this project-based model to grow into a sustainable solution and an accelerator for success stories such as the EEPLIANT3 CybPort application.

Today, Regulation (EU) 2019/1020 and the upcoming revision of the Ecodesign Directive retool Union MVE systems and unfold a handful of alternative propositions or blends of strategies for an organic integration of such smart tools with these policy instruments, and a level-field spread of innovation among MSAs.

Conclusions

Digitalisation and the application of software solutions have the potential to transform market surveillance in Europe. Tools like the CybPort tool for the upload of inspection data to EC's ICSMS under the EU-funded

[196] See conclusions in PROSAFE (2018), Final Report of Market Surveillance Action for Tyres 2015 - MSTyr15, pp. 16-17, at https://www.prosafe.org/images/Documents/MSTYR15/MSTyr_Final_Report.pdf (accessed 22 April 2022); PROSAFE (2020), Final Report of the Energy Efficiency Compliant Products 2 Action - EEPLIANT2, at https://www.prosafe.org/images/EEPLIANT2/EEPLIANT2%20-%20Laymans_Report_v9_REV_20210709.pdf (accessed 22 April 2022). On the hurdles of the data upload to ICSMS and the importance of improving the process see also European Commission/JRC (2020), Good Practices, pp. 20-21.
[197] Apart from the management of legal issues such as background, intellectual and ownership rights.

EEPLIANT3 Concerted Action are enabling MSAs to accelerate and scale up market controls and the exchange of information on non-compliant products. For bringing EU market surveillance to scale and decoupling it from shortages in resources, evidence suggest that digital transformation seems to be the way forward. The integration of smart tools in national market surveillance systems allows MSAs to remove cost burdens for tasks that can be fully or partially automated, while at the same time mitigating the existing gap of national resources available to market surveillance across the EU Member States. This leads to more efficient market controls with optimal use of the available human, financial, and technical resources.

Despite the benefits, the adoption of innovation remains variable among the EU MSAs. Experience from EU-funded market surveillance projects indicates that long-term maintenance and operating costs affect the longevity and level of commitment of MSAs to IT solutions developed in the context of EU projects. Consequently, a new business model is required to achieve sustainable innovation in the context of Regulation (EU) 2019/1020.

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Product Registration Systems (PRS) as a tool to transform markets in ASEAN to energy-efficiency

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Abstract

The implementation of energy efficiency policies to drive the market toward higher efficiency products is a multifaceted effort that requires a wide variety of stakeholders to work in unison.

Proper information management among those stakeholders is key to ensure the correct implementation and regular update of the policies developed. In particular, market surveillance and enforcement mechanisms, market transformation programmes, and financing mechanisms benefit enormously from a trusted and centrally managed Product Registration System (PRS). In this context, a PRS is used to capture specific information on products to underpin policies or programs and to provide an initial compliance gateway for products to enter into the market. It serves thus as a product data repository, market monitoring platform, and communication interface with the various stakeholders.

United for Efficiency (U4E), together with the ASEAN countries, has developed a product registration database that harmonizes product registration activities in the region to transform the regional market to energy-efficient lighting, refrigeration and air conditioners. The leveraging effect of regional coordination enables governments to reduce costs for product registry activities significantly and enhance the enforcement of the regulations in place while avoiding dumping grounds. In addition, countries of the region that do not have a national PRS in place can use the prototype national PRS developed by U4E.

The product registration framework, which can be also implemented by other countries and regions, is a fully functional system based on best practices. It includes a modular design that enables the users to individualize the systems and is also designed to work with slow connections and data requests.

1. Introduction to PRS

In many developing countries inefficient products that consume unnecessarily large amounts of electricity are being circulated and cause an added strain on the electricity grid. A key tool to transform the markets to energy-efficient products is a Product Registration System (PRS). Without a PRS, a market cannot monitor what is sold on the ground, which enables inefficient products to stay on the market. In other words, without surveillance of the products imported and sold, policies such as Minimum Energy Performance Standards (MEPS) are not effective. Along with other market surveillance tools, PRS puts in place an initial compliance gateway for markets and assists with the circulation of compliant products in the market.

The concept of PRS is simple and consists of four typical steps. First, the product that a manufacturer, importer or distributor wants to sell needs to be tested by an independent test laboratory or a conformity assessment body. This is done by selecting samples of the product and testing these in accordance with the applicable standard, such as by testing the energy efficiency of an air conditioner according to the MEPS of a country. Second, the applicant -- which is the manufacturer, importer or distributor of the tested product -- opens an account in the PRS and completes an application form for approval of their product. The application form typically requests information about the general applicant and product details, as well as product-specific information. This may include, for instance, the type of refrigerant used in an air conditioner along with test details and the test certificate. Third, a representative of a government agency (e.g., the regulatory authority) reviews the submitted application and accompanying documents for compliance with the requirements of the applicable standard. And last, if the review confirms that the product complies with the government regulation, then the regulatory authority approves the product for import and sale.

A PRS has many benefits, such as the above-mentioned ensuring of compliance with national policies through monitoring of the market. In addition, a PRS creates a database of product information that is particularly helpful when a country wants to develop new policies. For example, policy makers that want to implement

MEPS need to ensure that these standards are set at the right level. Well-designed MEPS remove the least efficient products from the market and leave only more-efficient options that are still affordable to consumers. If MEPS are not set correctly, they can have vastly negative effects, such as by specifying products with efficiencies that are not available in the market of the country or by not eliminating the inefficient products. In the absence of a PRS, several studies or market assessments need to be conducted in order to know which products are in the market. A PRS can greatly facilitate this process by providing policy makers with detailed and current data about the products in their country. In addition, policy makers can use the database to access baseline data and track efficiency trends and improvements; these can be used, for instance, in the reporting for Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). Another key benefit of PRS is that trade barriers are reduced by creating transparent market regulations and protecting manufacturers that comply with requirements. Manufacturers that comply with regulations such as MEPS get understandably frustrated when non-compliant manufacturers are still able to sell their products on the market. Setting clear rules that require all manufacturers to go through the same transparent energy efficiency certification process and follow the same requirements fosters economic development as testing and compliance costs are saved. In addition, PRS also foster economic development as they facilitate energy efficient products to become widely available in the market and adopted by consumers as well businesses, in which they also benefit from lower operational costs. Lastly, by adding consumer-friendly options such as scannable QR codes, PRS can also enable consumers to access the database to compare market offerings and make informed choices about the energy efficiency of products and lifetime costs.

Today many countries, such as Australia, China, Europe, India and the United States, use PRS. These systems all have a similar goal -- to underpin the countries' efficiency policies – but they are conceptualized in different ways according to the needs of the country and/or region. In general, countries either use stand-alone systems that serve as a national PRS for one country alone, such as in India, South Africa or China, or participate in a regionally coordinated system used by several countries as for example in the European Union or the Pacific Islands. National systems can have several formats; for example, the Indian PRS allows applicants to submit applications either online or offline by sending hard copies to the government agency [3]. The European Union uses the regional system and has recently updated its PRS. The European Union's PRS covers more than 30 products and is used by all of the countries of the region [1]. Another regional system is used by the Pacific Community, where one single web facility supports multiple countries [2]. In this system, applicants are requested to submit applications in one country only through a single platform which connects all countries. This registration process enables products to meet import or retail energy efficiency requirements of each member country. Unlike the European Union PRS, each country that uses the Pacific Community PRS maintains sovereignty over – and the right to approve or cancel -- its own records.

A regionally coordinated or harmonized PRS platform has many benefits, for example, when different MEPS levels exist within one region – a coordinated PRS helps to support the harmonization of MEPS policies and prevent specific economies in the region as dumping grounds of inefficient products. If several countries want to collaborate within the context of a PRS, there are four main technologies for sharing product registry data. One involves installing Web Application Programming Interfaces (APIs) in the national PRS that collect data from these systems and store it in a regional database. This technology is used in the ASEAN region's recently launched regional product database (see further details below). If countries decide to conduct the needed software maintenance at the regional database instead of the national PRS systems to save cost, then Long Term Support (LTS) Applications can be installed. These applications are product lifecycle management policies under which a stable release of a computer software is maintained for a longer period of time than the standard edition. A regional system with daughter LTS applications enables centrally organized maintenance. The final two options require a higher level of cooperation within a region: 1) In a regional PRS where all countries use one single system, the system centrally managed and all data are shared; and 2) lastly an innovative technology called a blockchain PRS. In this decentralized model all participants maintain a copy of the shared data, so the system is an inter-institutional and inter-market platform.

2. Overview of the project in ASEAN

In September 2019, the ASEAN Energy Ministers decided at the 37th ASEAN Ministers on Energy Meeting (AMEM) that the ASEAN Energy Database System will need to be enhanced to support the strategic objectives of the ASEAN Plan of Action for Energy Cooperation (APAEC) towards achieving energy security and sustainability for the region. This important milestone highlighted the necessity of developing a collaborative approach on product registration activities in the region.

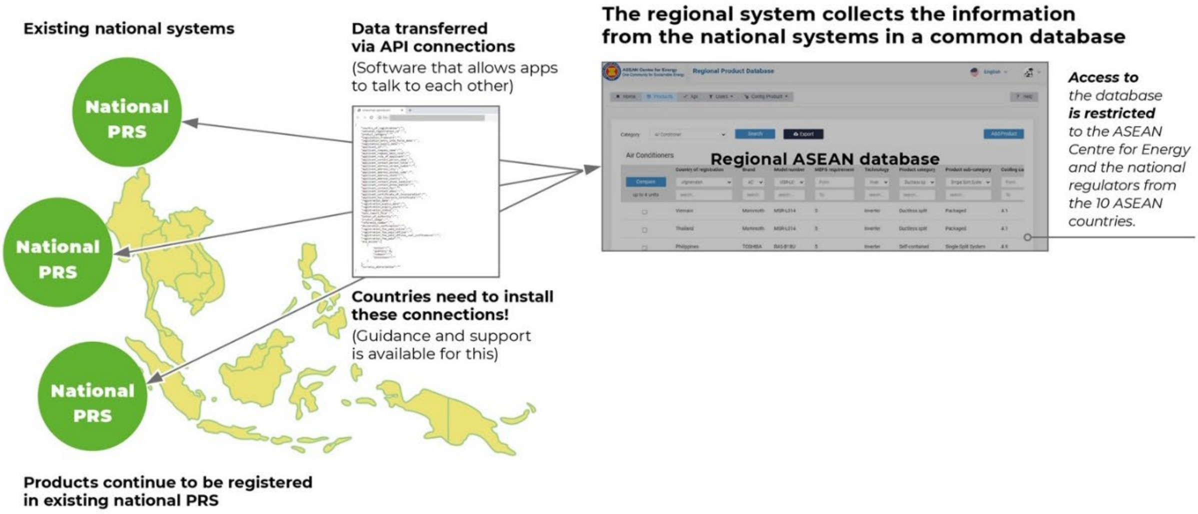
As of December 2021, only six ASEAN member states had developed PRS to support the implementation of their MEPS and labeling programs. These PRS vary in their design, function, and product coverage, depending on the scope of the MEPS and labeling program in each country, and they are operationalized in various forms: Some are only paper-based, some are paper and web-based, and some are only web-based systems. Other ASEAN countries, such as Brunei Darussalam and Cambodia, have started the PRS development process and are at different stages of implementation. Adopting a regionally coordinated approach for product registration in the ASEAN region brings significant benefits compared to maintaining different systems within one region. As discussed above, the leveraging effect of regional harmonization enables governments to significantly reduce costs for product registry activities and enhances the enforcement of the regulations in place while avoiding dumping grounds. With this context in mind, the United Nations Environment Programme's (UNEP) initiative United for Efficiency (U4E) and the ASEAN Centre for Energy (ACE) have started to work together to develop a regionally coordinated approach on product registration activities for ASEAN.

The project was kicked off with a regional workshop in Bangkok in February 2019 to inform the countries on the concept and benefits of a coordinated PRS and to learn from the countries about their PRS status and their experience on the topic. The workshop also included discussion on possible harmonization approaches. The following four approaches were discussed:

- A: All countries will stay with individual systems and develop APIs to enable communication and data exchange between each individual system and the regional database. Basic product data (e.g. energy efficiency data of products) from the regional database will then be available to all of the countries of the region for monitoring, verification and enforcement activities.
- B: The countries that currently do not have a PRS will adopt a master product registration framework as their national system, which will then be independently maintained by the country. The countries that already have an existing PRS in place will keep their systems and build a Web API or data transfer interface to allow access to the regional database.
- C: One master product registration framework will be adopted as a national PRS by all countries that wish to do so.
- D: One single PRS in the region will be centrally managed and all data will be shared among countries.

During an online follow-up meeting in May 2020, discussion about the different approaches continued and it was decided that a mixture of options A and B would be developed, as outlined in Figure 1 below. The countries will continue to operate and manage their own PRS, which will be connected to a regional product registration database. The regional system collects data through APIs that will be installed in the national PRS. Because the database contains confidential information, access is restricted to government officials only from ASEAN as well as ACE. In addition, countries that do not currently have a national PRS in place will given the opportunity to implement a national prototype PRS system that is developed by U4E. This prototype system has the API directly included and thus enables a direct connection to the regional database.

Figure 1. Data exchange in ASEAN



To implement the agreed approach, ACE and U4E developed a roadmap that outlines each of the detailed steps as well as the timelines, and a Technical Working Group (TWG) was set up to guide the software development. The Working Group consisted of a member from each of the ASEAN member states as well as the database project team, which included representatives from ACE and U4E. With the support of the TWG who delivered indications for the data exchange, common datapoints were developed for the exchange of data on air conditioners, refrigerators and lighting; these datapoints will be transferred from the national systems to the regional database. The datapoints were selected to enable ACE and the countries to track the most important information on the products that are currently available in the countries, with priority given to information on the energy efficiency of the products. The guiding principle for the selection of the datapoints was that they should facilitate the harmonization of data collected. For example, information regarding refrigerant gases is collected based on the type of refrigerant, not on the Global Warming Potential (GWP) or Ozone Depletion Potential (ODP) values contained in the national systems, as these may vary depending on the reference utilized.

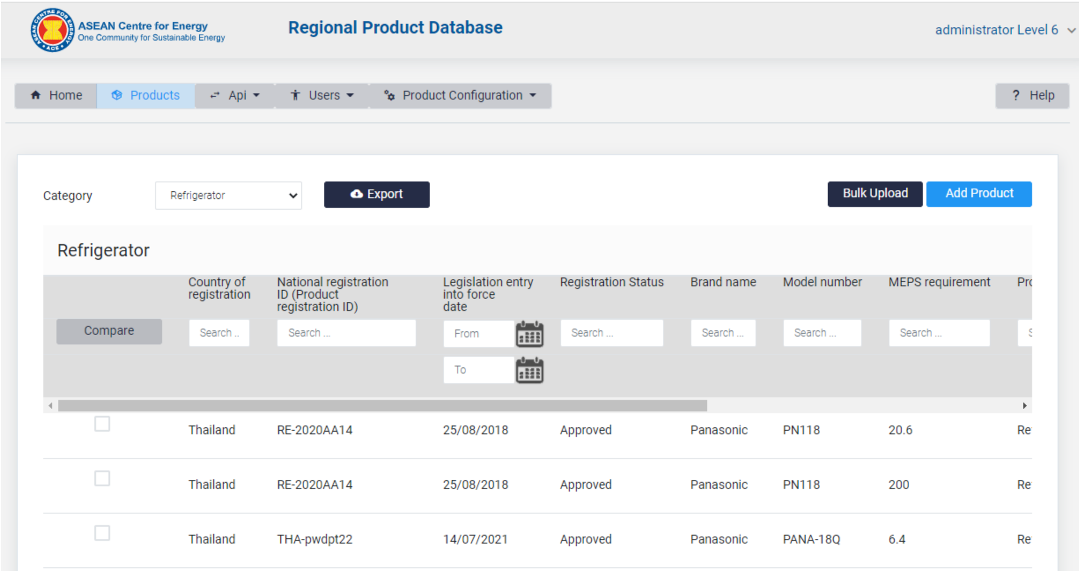
As the initial step of software development for the regional database as well as the U4E national prototype, an outline (wireframe) document was drafted for discussions with TWG and ACE. The second step was to create a development version ("draft software"); this has been reviewed by all project stakeholders and additionally verified by U4E's lighting and cooling experts. Thereafter the software went through several rounds of testing to make sure it was working correctly, and the final version was developed (see more information on the software development below). Lastly, the software was transferred to the final server and taken over by ACE, whose representatives are managing the regional database.

3. Regional ASEAN product registry database and prototype national PRS

The regional ASEAN product registration database was created to support the monitoring of energy-efficiency in the region on three key products: lighting, air conditioners and refrigerators. Through this database the ASEAN countries will have visibility of products that are allowed for sale throughout the region and will receive notification when new products are granted access to the market or when products are revoked. For example, if a new importer of air conditioners applies for access to the market of a new model in Thailand and Thai public authorities find that the product is not compliant with their MEPS (e.g., if the air conditioner model has a high Global Warming Potential (GWP) refrigerant), then this information will be transferred to the regional database. The other countries of the region will receive notification that the air conditioner model is not being granted access to the market in Thailand. Based on this information the government officials from each country can verify on their respective PRS whether this air conditioner model is compliant with their MEPS. If it is found compliant then these countries will ideally reevaluate their policies to upgrade their MEPS in order not to serve as a dumping ground for inefficient and high GWP air conditioners.

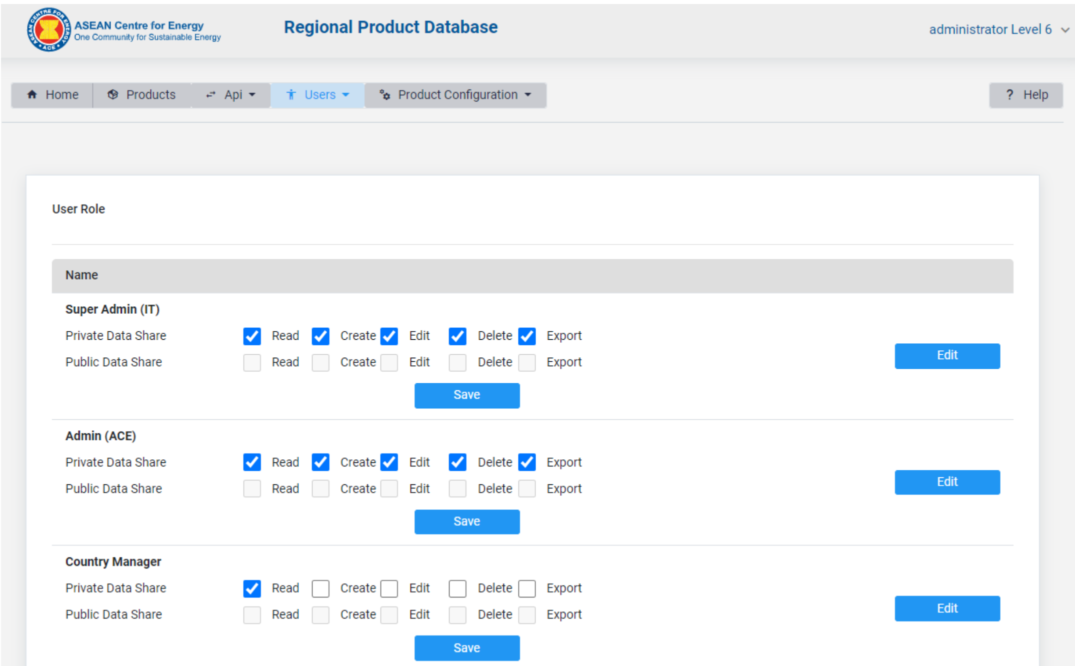
Figure 2 gives insight into the regional ASEAN product registration database with an overview of the registered products (dummy data). As noted, the information on the products comes from the ASEAN member states when they connect their PRS to the regional database via API or through manual data entry (either single or bulk upload) by ACE. The database allows users to compare up to four products, to filter the products according to the categories in the top bar, and to export the selected products into an excel document.

Figure 2. Overview of registered products



The information that can be accessed by the member countries, who have read-only access, can be enabled by the administrator of the database, which will be represented by ACE. In addition to the ability to enable or disable product data, the administrator has also can change and manage the user roles (see Figure 3).

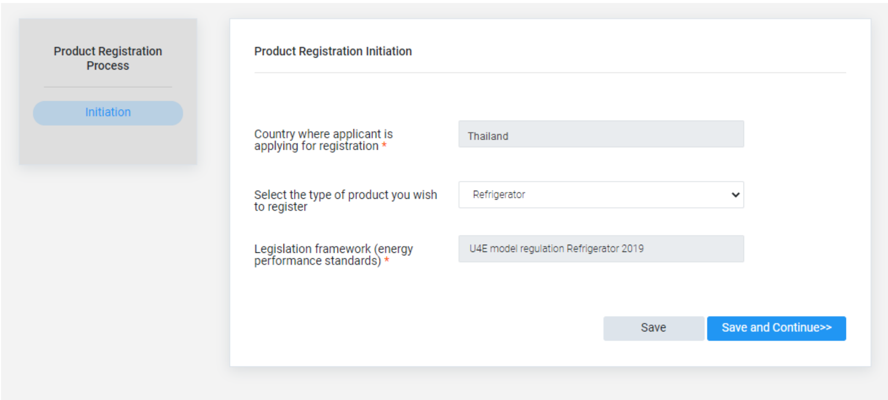
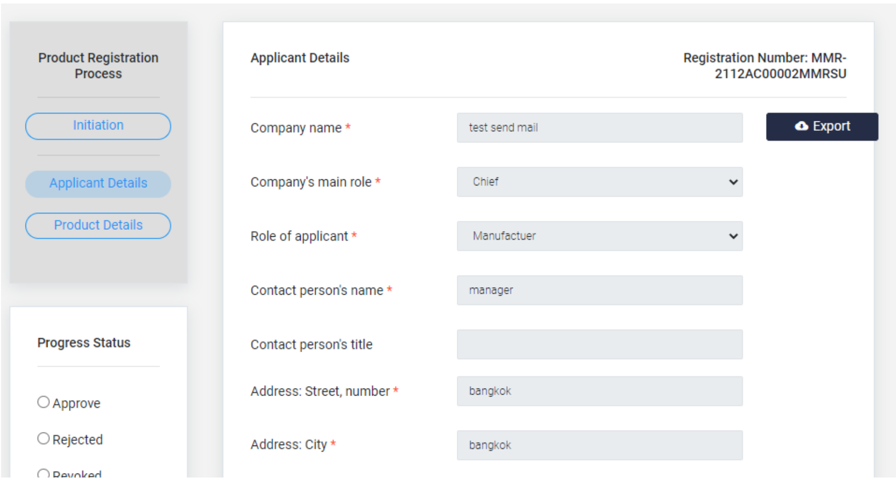
Figure 3. User roles of regional database

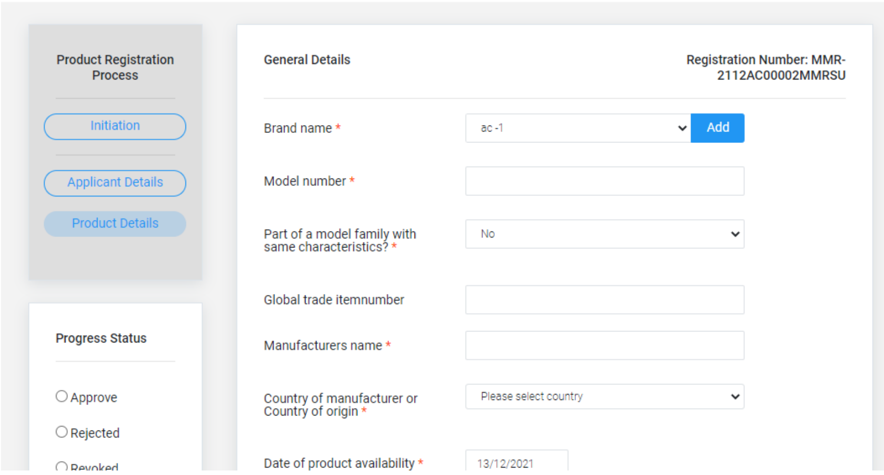
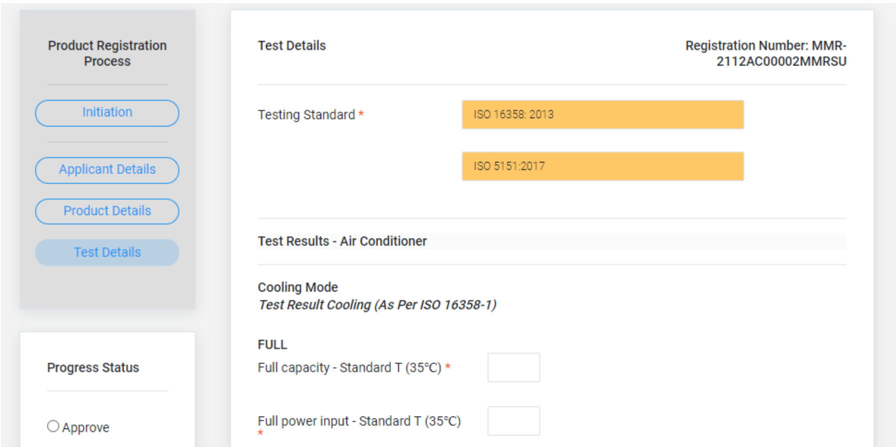
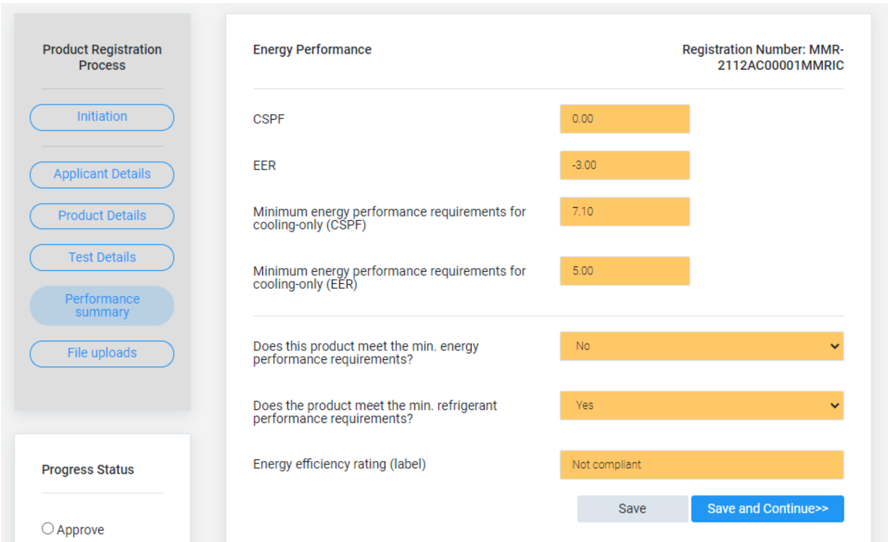


In addition, the database contains an overview of the API connections from the countries, which are also managed by the administrator. To guide the countries in setting up these connections the database contains instructions on how to register a user and an API client account as well as a guide for developers, API tutorials and references. A general database help area also exists to guide the users through the system.

In addition to the regional ASEAN database, U4E has developed a prototype national PRS that can be implemented by ASEAN countries that do not already have a national PRS in place. Both the prototype and the regional database are based on an open-source software which is designed to work with slow connections and data requests -- which are often the case in developing countries. Moreover, the prototype is built using best-practice functionalities that can be personalized by each country that wants to implement it. The prototype contains a six-step product registration process that needs to be completed by the applicant, as presented in Table 1 (with dummy data):

Table 10. U4E prototype application process

Initiation of the application with basic information on where the product is being registered and according to which legislation.	
Requested information on the applicant, such as contact details and tax clearance certificate.	

<table>
<tr>
<td>General questions on the product as well as appliance-specific details, e.g., cooling mode and refrigerant data.</td>
<td>
</td>
</tr>
<tr>
<td>Questions about the testing of the product, such as the applied testing standard and the metrics used for testing.</td>
<td>
</td>
</tr>
<tr>
<td>Summary of the energy performance of the product.</td>
<td>
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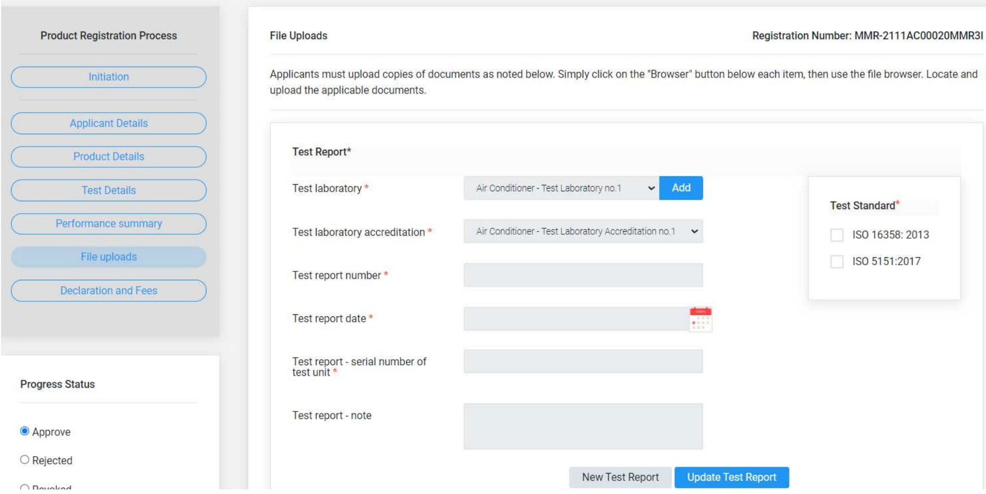
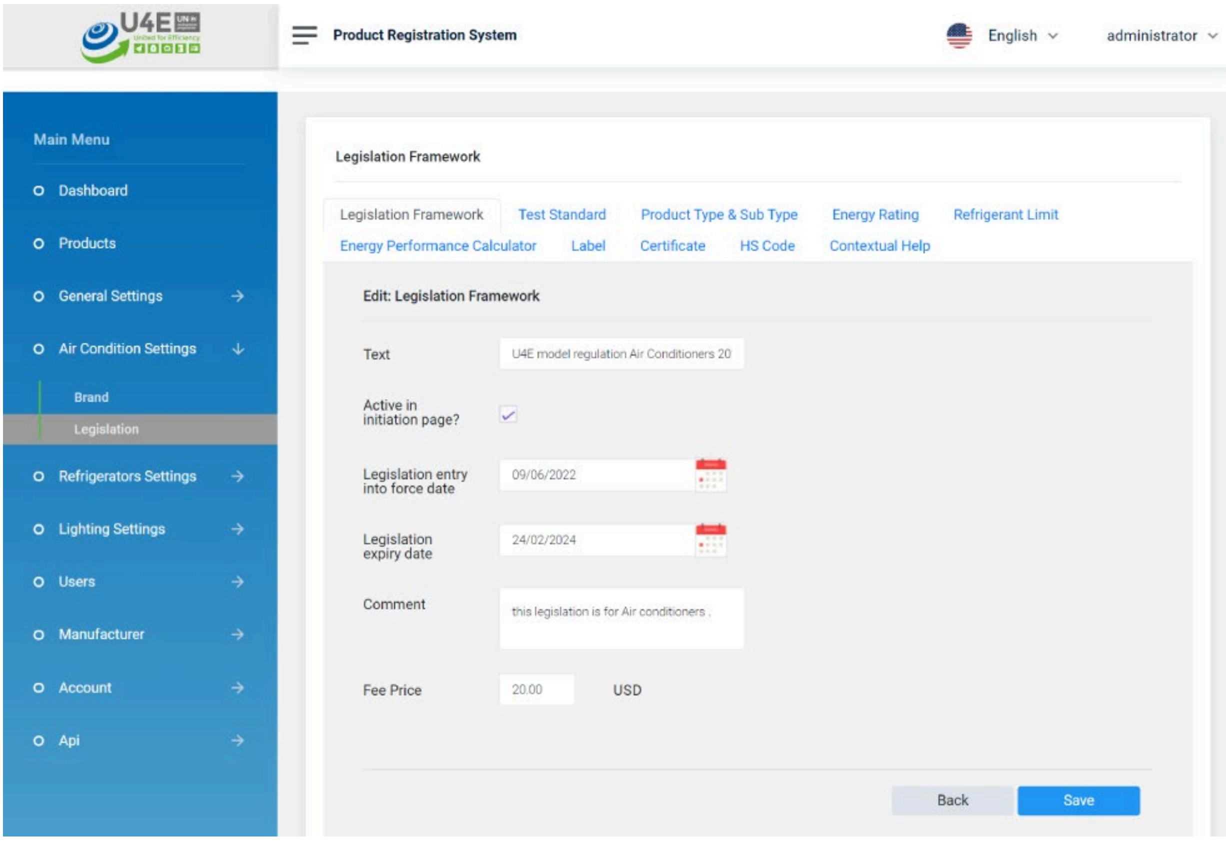
Upload of files including testing details, letter of authority, and an (optional) image of the product.	

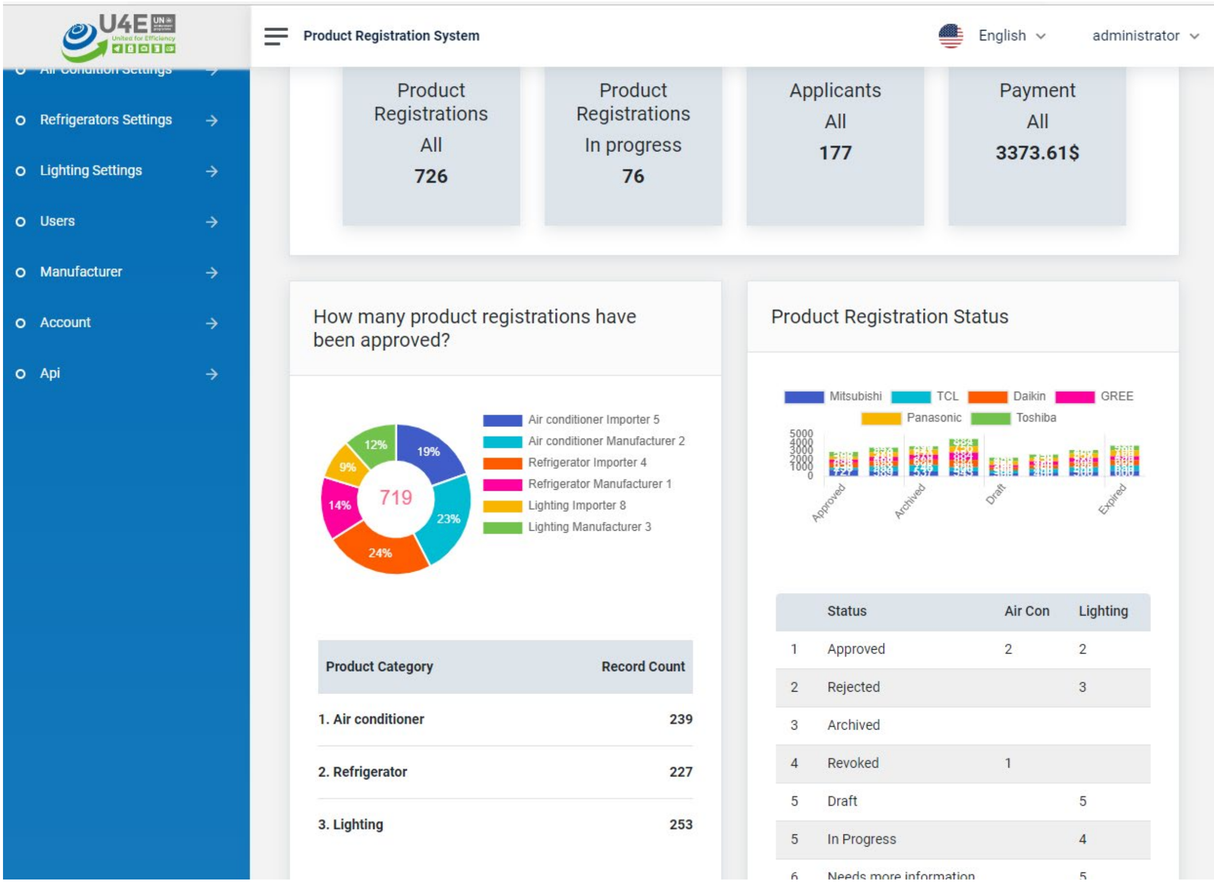
As a default legislative framework, the prototype uses the U4E model regulation guidelines, which are best practice guidelines for developing MEPS; these guidelines are currently being implemented by Rwanda [4]. The legislation framework can be modified according to the countries' needs, as Figure 4 shows. Additional features that can be personalized include a bulk upload and the personalization of the product categories. The personalization of features is described in more detail under the section software specifications.

Figure 4. Legislation framework of U4E prototype



The prototype also contains a dashboard that shows an overview of the products that have been registered in the system (Figure 5) along with key data, such as the brands of the products or the product registration status.

Figure 5. Dashboard of prototype



Both the regional ASEAN database and the prototype currently contain data on lighting products, air conditioners and refrigerators. Both systems can be easily upgraded to include additional products.

3.1. Description of software specifications

The development of the systems was based on best practice software specifications which were developed through a comparative analysis of existing PRS in other countries. The software specifications [5] include the functional description of the software, user interface pages, datapoints, database schema, and user levels. Based on these software specifications, countries are enabled to develop their own systems.

The prototype national PRS was developed based on these software specifications and additional requirements, such as the implementation of a legislation-based configuration. The list of functionalities that the U4E prototype PRS contains is below:

- Legislation-based configuration: The tool allows creating, duplicating, and editing “legislation” applicable to the products being registered. The tool includes::
  - Product categories and subcategories
  - MEPS and label thresholds per sub-category
  - Definition of parameters used in the assessment (e.g., Energy Efficiency Ratio (EER), Cooling Seasonal Performance Factor (CSPF), Coefficient of Performance (COP) for air conditioners, weather profiles).
  - Content and layout of certificates and energy labels
  - Registration fees per product
- Multiple user roles: Administrators, Monitoring, Verification and Enforcement officers, Customs officers, Manufacturer/Importer administrator, etc.
- Product registration lifecycle management: Definitions and process for product applications
- Multi-language user interface

- Contextual help text editing by administrators
- Energy efficiency calculation from test reports data entry: the PRS calculates energy efficiency parameters (such as CSPF for air conditioners, or Energy Efficiency Index for refrigerators)
- Bulk upload of product data can be submitted as part of the registration
- Modular design: Data structure is designed so that additional products may be added with relative ease
- QR compatible: Individual product pages that may be accessed with QR codes
- Fee processing
- Generation of certificates and energy labels
- Public portal that displays a limited set of information for the general public
- MVE records that allow MVE and Customs officers to keep a log of MVE actions taken on the registered products (e.g., results of third-party tests, other non-compliance results, log import quantities)
- Notification system: Users are informed of changes to the registration status of the products.

The specifications required the use of Open Web Application Security Project (OWASP) Secure Coding Practices, and a Level 2 of its Application Security Verification Standard (ASVS) v4.0. In addition, a set of safety features was implemented, including the storage of sensitive user data using strong hashing techniques, use of the latest TLS communication protocol for all data transfers, management user sessions with timeout periods, and encrypted storage of uploaded files. In addition, the development was done in a flexible framework that allows multi-platform deployment (on-site/cloud, windows/linux), and an optimized operation that can handle slow/unreliable internet connections. The platform chosen was Node.JS, which allows deployment on a wide range of scenarios, is asynchronous in nature (improving user experience in slow connections), and uses JavaScript as its only programming language.

The regional ASEAN database was developed based on these software specifications and includes a simplified version of the above-mentioned specifications.

3.2 Software Development Process

Both the national PRS prototype and the regional ASEAN database were developed based on a master PRS framework. The PRS software development process[198] was divided into seven steps, which were followed to ensure that the PRS is built correctly and that the systems are well designed to meet users' requirements. In the whole PRS development process, the first step involving gathering and analyzing the PRS requirements was the most critical for ensuring that the PRS meets its development objectives. Step 1 thus guides the remaining development steps and also the coding under Step 5 is important because proper coding promotes the integrity and security of the system. The development steps are shown in Figure 6 and the details of each step are discussed below:

Figure 6. PRS Software Development Process

Step 1: Gathering and Analyzing Requirements: This was the most critical step of the software development process. A comprehensive set of requirements was defined for the PRS software as well as business needs and applications of the PRS, features, functionality, and user behaviors. For the PRS development, the overall system requirements were primarily based on the above-mentioned PRS specification document.

Step 2: Designing & Creating a Mockup: Once the goals of the application were clearly defined, an online interactive mockup was created to validate these requirements and allow for realistic testing. For the PRS development, a mockup was built to represent both visuals and functionality of the PRS and enable understanding of the user interface. The data set is based on the U4E model regulation guidelines for lighting, appliances, and equipment.

Step 3: Testing & Evaluating Initial Users' Feedback: The mockup was presented to users to evaluate and identify usability issues, navigational structure, design flaws, and errors. This testing and evaluation step enabled the development team to get early feedback on potential improvements and changes and to verify the accuracy of requirements

Step 4: Refining Mockup: The mockup was further refined to eliminate the errors found and to achieve a successful result.

[198] A software development process is also known as a software development life cycle (SDLC)

Step 5: Building & Coding a Prototype: An actual working prototype and its database were then designed based on the requirements gathered and the approved final mockup. For the PRS software, the prototype was coded by using NodeJS. The coding/programming task was divided into multiple components including user role management, access control list, and product registration management subdivided into each product type. Coding/programming of these components was undertaken both sequentially and in parallel depending on their workflows. In addition, specify parameters to calculate energy efficiency values for each product type were used to design and create a calculation module to perform validation checks on the product approval process in the system.

Step 6: Refining, Debugging & Retesting: This step was performed to ensure that the prototype is fully operational. The test and debugging process continued until the software was bug-free and stable.

Step 7: Releasing & Maintaining: Once the coding and testing steps were completed, the PRS software was deployed on the server and released for public access.

4. Current Status and Conclusion

The harmonized product registration database will facilitate the transition of ASEAN's markets to energy-efficient cooling and lighting, while the national prototype will support countries that do not have a PRS in a coordinated manner. The database was launched during the 39th ASEAN Ministers of Energy Meeting (AMEM) on 15 September 2021, which noted the Strengthening of Market Verification and Enforcement Capabilities that the database will bring for the region. ACE has taken over the software at the end of 2021 and is currently making internal arrangements to start the implementation with the countries.

At the same time countries that do not have a PRS in place are being proposed by U4E and ACE to implement the prototype system. Individual technical assistance has been delivered in this context to Lao PDR which might result in a future implementation of the system. Also, other regions showed interest in the national as well as regional system and currently discussions are underway in Southern Africa.

The ASEAN region is a pioneer in implementing a regionally coordinated product registration database, as it is one of the first regions of developing countries to exchange product registration data in a collaborative manner. Transforming the markets of ASEAN to more energy-efficient cooling and lighting is of critical importance as the energy consumption for these products is predicted to rise extremely within the next years. The regional product registration database helps the region to determine the efficiency of the products that are circulating in the region and thus to align policies at a regional level. The project has in that context developed with country officials and together with ACE a tailored database that is complemented by a national prototype to support the region in achieving the numerous benefits of a PRS.

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Achievements in consumer relevant product testing

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Abstract

At EEDAL 2017, a general methodology to assess the consumer relevance of test methods was presented, offering a first step towards more systematic assessments of test methods. In addition, at EEDAL 2019 findings from first implementations of the methodology have been presented and discussed as well. This paper is summarizing tangible achievements with regards to new EU regulations which are meanwhile in effect for refrigerators, washing machines, washer-dryers, and dishwashers. An overview of recent achievements and underlying issues and possible solutions will be provided and discussed.

In view of the new EU regulations on energy labelling and ecodesign, there was the need to completely revise test procedures. This circumstance was welcome in order for test procedures to better represent real conditions of use. In addition, the requirements set by the regulations themselves were also included with regard to this aspect.

For washing machines, the loading in particular was adapted to reflect better the user habits. Another new element is that the test procedure is supplemented by additional procedures for determining the rinsing effect and the maximum temperature to which the textiles are exposed during washing. For refrigeration units an approach was adopted, measuring the energy efficiency under two ambient temperatures covering the range of consumer relevant ambient conditions. For dishwasher testing the variety of dishes was expanded, now also including plastic items, pots and mugs. A new market-relevant detergent was also introduced. These examples of achievements have been validated. In addition to the presentation of these achievements, ways are also shown to transfer the knowledge to test procedures of other appliance categories analogously.

All of the achievements of a more consumer relevant testing have been achieved without deterioration in the other relevant requirements of a standardized testing procedure: repeatability (within on test house) and reproducibility (between test houses). However, test burden did increase, for some products substantially, like for washing machines and washer-dryers.

Introduction

Consumer relevant testing procedures provide results that correspond to findings obtained when consumers use the product in their daily lives. The results shall be representative. This is a challenge because consumer relevant testing is still conducted in a laboratory environment, where testing must be repeatable, reproducible, and at a reasonable cost level.

CENELEC Technical Committee 59X *Performance of household and similar electrical appliances* was developing a methodology for determining all these aspects. Reports have been given to EEDAL conferences in 2017 and 2019 already, see [1] and [2].

Basically, it is finding a balance between the competing criteria representativeness, reproducibility, repeatability and cost, as described in [2] and [3]:

> *"Representativeness: The correspondence of the results from applying the test procedure to the results obtained in practice (with the end users);*
>
> *Reproducibility: The consistency of results when the same product is retested under somewhat different conditions, for example, in another laboratory, but using the same test procedure;*
>
> *Repeatability: The consistency of results, for example, regarding energy consumption or performance when the same product is retested under the same conditions, for example in the same laboratory by the same staff;*
>
> *Costs: The costs of carrying out the test procedure."*

It is important to note that this approach is in close correspondence with the new EU framework regulation on energy labelling (see [5]) and related product specific regulations (see below). Requirements set out in those regulations have been intensively discussed with regulators and stakeholders in advance in consideration with the approach. Several workshops have been held also. New standardisation requests from the European Commission on washing machines, washer-dryers and dishwashers [6] and refrigerators [7] do not directly make a link to the methodology. However, it reveals that the methodology and results have been very beneficial for the implementation (see below).

Meanwhile the technical committee was working on further products as well. Assessment tables as set out in [3] have been worked related to further product categories (see below).

The technical committee is also preparing annual reports for the documentation of achievements for each product specific standardisation activity, see [8] and [9]. The annual reports are for internal purposes. For standardisation working groups these annual reports are beneficial, because they are summarising the work done in a special format. It makes transparent the status where a project was and where it is at the moment related to the methodology. It is therefore a tool for learning and improving own practices of the inclusion of more consumer relevant aspects in laboratory test standards.

Anti-circumvention

Besides the issue of consumer relevant testing the annual reports are documenting the achievements related to anti-circumvention also. It revealed that the combination of both issues in a unique report is of benefit as both issues are linked to each other. Anti-circumvention means, preventing the use of sensors for detecting the test cycle or the test environment and modifying the process accordingly for better performance. Clearly, this use would be in vast contrast to consumer relevant testing as consumer relevant testing is requesting always more representativeness than what is in the pure test cycle conditions in an unlawful behavior. Thus, achievements in anti-circumvention are achievement in consumer relevant testing also.

Within the EU HORIZON 2020 Project ANTICSS a definition of 'circumvention' and 'jeopardy effects' with regard to EU Ecodesign and Energy labelling legislation has been developed, and published in 2019, which clearly delimitates the act of circumvention from non-compliant products and other effects, see [10]. Based on the ANTICSS definitions of 'circumvention' and 'jeopardy effects' recommendations were derived to support policy makers and standardisation bodies to prevent future circumvention under EU ecodesign and energy labelling. Additionally, the CEN-CENELEC Ecodesign Coordination Group (ECO-CG) developed guidelines is "To provide guidance and support to standardisers on Ecodesign and Energy labelling for a systematic consideration of the issue of circumvention in the development of standards". The objective is to raise awareness within the relevant standardisation technical committees and their working groups by providing examples of circumvention cases and giving recommendations on how possibilities of circumvention can be reduced or minimised when developing measurement standards. Both initiatives were broadly discussed within TC59X and provided valuable input in revising the measurement standards.

Noise aspect

For acoustical noise it is even more difficult integrating consumer aspects in the measurement standards. This is because the tests have to be performed in special noise test chambers.

The infrastructure of such test chambers requires the installation and loading of appliances as well as the environmental conditions normally to be of a minimum complexity. E.g. soiling of dishes for testing dishwashers cannot be done. However, according to the last revision of EN 60704-2-3 the test includes now detergent and rinse-aid, a larger variety of dishes and an injection of defined milk for simulating the turbidity of the water. This mechanism guarantees the dishwasher under test is working closely like a dishwasher is filled with soiled dishes. This effectively widens the consumer representativeness. At the same moment this is also a means for preventing circumvention as well.

Furthermore the limited number and availability of such chambers for appliance noise emission testing suggest to develop reduced testing conditions so to limit the number of tests needed and make it feasible with available resources. As consequence, as matter of fact, testing noise in various program cycles is still not possible for economic cost reasons.

For acoustical noise testing according to EN 60704 it is essential to align the loading, the process conditions and environmental conditions along the performance testing. To get a coherent set of results the operating conditions for noise tests are aligned as much as feasible to performance and consumption tests. This ensures that properties of a product cannot be optimized to corresponding noise test conditions.

In addition all new or revised noise test standards are assessed regarding their consumer-relevance according to above mentioned systematic assessment method.

Achievements related to product categories

General

The methodology of CENELEC TC59X (see [3] and [4]) has been implemented successfully in the working program of the working groups of TC59X. First results have been reported already at EEDAL conferences 2017 and 2019, see [1] and [2]. In this section further achievements are reported. It is also shown that achievements were well recognized. They have been considered in new EU regulations on energy labelling and eco-design for washing machines, washer-dryers, dishwashers and refrigerators, see [11].

Washing machines and washer-dryers

The revision of EU regulations on labelling and ecodesign for washing machines and washer-dryers resulted with a standardization request into an update of the washing machine standard EN 60456 and a new washer-dryer standard EN 62512 based on the international standard IEC 62512.

For two additional consumer relevant criteria for washing, rinsing performance and actual washing temperature, test methodologies were developed and published as technical specifications.

Measuring the rinsing performance makes sure that there is a good compromise between water consumption and removal of detergent from the laundry. Resource saving should not harm needed performance.

The temperature measurement method described in the Technical Specification TS 50707 makes the real temperature inside laundry visible and allows consumers to decide themselves if hygienic needs require higher temperature or if energy saving low temperature programmes can be used.

The EU energy label for washing machines as introduced in 2020 is based on a new washing programme called Eco 40-60 program, tested with ¼, ½ and full load. As there are three loads, it is necessary to optimize a laundry appliance for the full range of capacities, which are consumer relevant.

The energy label for washer-dryers is based on 2 test methods. One is for washing only and the other is for drying. Washing is like testing a washing machine. The drying test, called wash and dry, tested with half load and full load, starts with washing (ECO 40-60 program) and ends with drying to cupboard dry. This test runs without interrupting the process (continuous operation cycle).

The next revision of the standards EN 60456 and EN 62512 is necessary because regulations were amended. This update will include refinements regarding the measurement of low power modes, taking into account the more and more relevant status of connected appliances.

Dishwashers

The work on revising the test methodology for household dishwashers started very early on as the need for a more consumer relevant approach was clearly seen for a procedure that had not had changed substantially for more than 20 years. Also in anticipation of a future revision of the EU Energy label European stakeholders proposed new test approaches in 2011 on IEC level for the international standard IEC 60436, which were extensively researched and discussed. In 2015 the 4th edition of this standard was published, which included the following relevant changes:

- More consumer relevant dish load items: The performance of dishwashers is tested with a defined set of dishes, so called place settings (the number is depending on the rated capacity of the test unit) and serving pieces. Both elements of the test load were antiquated and represented more a family of the 1970s than today's households in terms of variety of shapes, materials, and number of items. For this reason, two types of place settings are now defined, which additionally include glass cereal bowls, porcelain mugs, and melamine dessert plates. The set of serving dishes was redefined to include a big glass bowl, two plastic bowls, a serving platter and two types of pots. Especially the inclusion of the plastic material melamine is seen as a consumer relevant change because the standard now puts more emphasis on challenging the drying performance of modern dishwasher technology. The bigger variety of shapes and forms was intended to allow for a more useful design of dishwasher baskets in the daily use of consumers.
- Market relevant reference detergent: The used laboratory detergent was updated to better reflect the performance of market detergent, which have more effective ingredients, such as enzymes, bleach components and builders. With this change the total amount of applied detergent was significantly reduced (for a dishwasher with 12 place settings the dosage decreased from 30 g to 20 g) and is therewith closer to current dosing recommendations of market detergents.
- Combined Cleaning and Drying evaluation: In previous versions of the IEC and European standard the assessment of the cleaning and drying performance of a dishwasher was done separately, where cleaning performance was tested first with a soiled load and then the drying performance evaluated subsequently with a clean dish load. As more and more dishwashers were equipped with soil-sensing technologies, this approach constituted a loophole, which made the detection of the test condition possible. Therefore, both types of performances are now tested on the same test runs, also reducing the testing time from two weeks to one week.

All those relevant updates and other changes were adopted on European level and are included in the EN 60436:2020, which is used to assess the current energy labelling and ecodesign requirements for this product.

Refrigerators

Besides the already several times reported (see [1] and [2]) modified test procedure to determine the energy consumption of household refrigerating appliance at two ambient temperatures (16 °C and 32 °C) instead of only determining it at 25 °C, there are additional new test items introduced in the latest EN 62552-1,2,3 published in 2020.

The testing of the appliances in two different ambient temperatures, in order to cover a wider range of installation conditions, forces the manufacturer to offer to the consumer a more sophisticated technology, well performing and energy efficient appliances.

The revised consideration of the energy consumption caused by a forced defrost cycle pushes exactly in the same direction: a more sophisticated design and technology is necessary to be able to produce efficient Nofrost refrigerating appliances.

The energy consumption as considered as follows: the incremental defrost and recovery energy consumption of a defrost cycle is calculated, means which additional energy is consumed compared to the energy consumption in steady state.

With this procedure the heat transfer from the defrost heater to the heat exchanger is considered, it is considered how good or bad the thermal insulation of the heat exchanger to its surrounding is designed and also how efficient the compressor is working while the recovery process.
In addition the manufacture have now to declare the minimum time (heavy usage) and the maximum time (low usage) between two defrost cycles. These times are then used as weighing factor for the consideration of the incremental defrost and recovery energy

With this revised consideration the contribution of the incremental defrost and recovery energy consumption to the overall appliance energy consumption is in average more than doubled compared to how it was taken into account in the predecessor standard EN 62552:2013.

This modification is getting of more importance since there is a significant market share increase of Nofrost refrigerating appliances in Europe year by year.

A further aspect in the standard leading to the consumer relevant determination of the energy consumption was introduced for built-in appliances, a significant market in Europe as shown in Table 1.

Table 1: Eu production and trade of refrigerating appliances, value in million euros (source: Prodcom, Eurostat, 2015)

Production	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
27511110 - Combined refrigerators-freezers, with separate external doors	1804	2002	1861	1463	1460	1651	1632	1841
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	1125	1262	881	646	625	578	601	548
27511135 - Compression-type built-in refrigerators	682	700	500	600	635	689	800	800
27511150 - Chest freezers of a capacity <= 800 litres	747	604	407	397	501	476	442	451
27511170 - Upright freezers of a capacity <= 900 litres	531	541	499	486	486	493	458	515
TOTAL PRODUCTION	**4888**	**5108**	**4148**	**3592**	**3707**	**3888**	**3933**	**4155**

The installation conditions for the laboratory tests are now more stringent and reflecting the situation in real kitchens regarding niche dimensions and the available space for the appliance itself.

Built-in appliance have to be tested in test enclosures. Especially the space in between the rear wall of the appliance and the niche rear wall plays a decisive role for the energy consumption.
Since there are different niche depths in the market (550 mm, 560 mm, 580 mm) and the manufacturer has to declare for which niche its appliances is suitable, it is now clearly defined which niche depth has to be used according to the manufacturer's declaration.
Example: manufacture declaration for the depth: 555 mm to 570 mm, the test enclosure depth has to be 560 mm

In addition to the above described procedures to determine the energy consumption, a further important field for the consumer is sustainability, for household refrigerating appliances mainly in the sense of reducing food waste by improving the storage conditions for different kind of food.

For sure it is not necessary to mention that storing food is the main task of refrigerating appliances.

Additional compartment types for specific kinds of food were defined, also taking into account that cooling appliance with more than two compartments are getting more and more popular. So the customer can be sure that also with these more compartment appliances a comparison between different models is still possible.

The fact that colder and stable temperatures in unfrozen compartments extends the shelf life time especially of perishable food is well known.

This was reflected with adding the chill verification test in the EN 62552-3:2020.

The chill verification test has to prove, that the chill compartment conditions are kept independent from the setting of the other compartments (fridge or freezer).

With this test it is ensured that the customer will have chill compartment conditions independent from the settings of other compartments of his appliance and without the necessity to readjust a slider or anything else in order to keep the environmental conditions for a long shelf life time for perishable food.

To conclude, the latest edition of the EN 62552 considers consumer relevant testing with different approaches.

Vacuum cleaners

Vacuum cleaners can be used by consumers in a wide variety of situations. For the most important applications, corresponding tests are to be defined in the standards. As part of a continuous improvement of the standards, existing tests are being assessed following the “Internal Guide on Consumer Relevant Product Testing of Household and Similar Electrical Appliances” [3]. New tests are being introduced, driven by demand of users of the standard, as shown in the following example, or by technological progress and development of the market, e.g. for battery-operated vacuum cleaners.

For consumers, it is important that vacuum cleaners not only pick up fine dust or hair, but are also able to pick up coarse material from hard floors and also from carpets. Earlier standards for measuring the performance of vacuum cleaners did not include any test regarding the removal of coarse material. This was often criticized as a major shortcoming of the earlier standards.

A few years ago, consumer testing organisations developed their own tests for the removal of coarse material. However, organic goods such as rice and lentils are used, which may be different from test to test. In the meantime, standardisation has also developed a test to determine the removal of coarse material for vacuum cleaners. The organic test materials are replaced with synthetic materials for which specifications or standards exist and that are widely available. Of course, the synthetic material corresponds to the organic material in shape, dimensions and weight, see Figure 1.

Figure 1: Synthetic coarse material as a substitute for organic materials (example):

Set screws (plastic) as a substitute for rice - Nuts (plastic) as a substitute for lentils

Source: Vorwerk Elektrowerke GmbH & Co KG

Ideally, a vacuum cleaner nozzle picks up coarse material not only in the forward motion but also in the backward motion – as in 'real life'. The new test allows a separate evaluation for both directions of movement.

A major challenge for future standardisation is the fact that cleaning appliances are becoming increasingly 'intelligent'. For example, some vacuum cleaners are already equipped with dust or motion sensors that help to automatically adjust the setting of the device, e.g. the suction power. Cleaning robots in particular pose a special challenge, as they interact with their environment in a multitude of ways. Here, the task is to define consumer-relevant tests and at the same time fulfil the requirements regarding complexity as well as reliability, accuracy and reproducibility.

Cooking Appliances

In view of the revision of the European ecodesign regulations for cooking appliances that has just been commenced, the methods for ovens, hobs and cooking fume extractors have also been analyzed. For a further improvement of the measurement of energy consumption relevant for a standard household use, the following improvements are currently being implemented in the respective standards:

Ovens

The oven volume, relevant for the relative energy consumption, should in future not be determined according to instructions for use, such as an instruction for yoghurt, but by means of clearly described measuring points in the product standard IEC 60350-1. The energy consumption is measured with a load, a water saturated brick. The reference temperature for calculating the energy consumption is measured in a second step in the empty oven. However, in both steps the oven temperature is measured and from this validity criteria are calculated, which ensures transparency about the thermal behavior of the oven in both steps

Hobs

Applying the TC 59X guidance approach [3] to determine the consumer relevance, the result has certified a high consumer relevance for the method of energy consumption measurement in IEC 60350-2. The inclusion of different cookware sizes independent of the hob design as well as the representation of an entire cooking process, i.e. the heating-up phase and continued cooking phase, are to be emphasized. In particular, the inclusion of the continued cooking phase also permits to assess how efficiently the cooking process can be controlled. Especially the control unit, i.e. how precisely the desired cooking level can be set with a mechanical, electromechanical or electronic component, influences the level of energy consumption.

Cooking fume extractors

Whereas fluid dynamic efficiency in IEC 61591 was previously determined only for the so-called best efficiency point, the new proposal includes 9 measuring points in the calculation. These 9 measuring points reflect different blower levels and consumer relevant operating points. This new calculation prevents an optimization of the performance only for one operating point and shows differences in blower technologies in a more sophisticated way.

Conclusion

At EEDAL 2019 conference it has been reported that the "process is ongoing" and a "final conclusion cannot be made", see [2]. Meanwhile the methodology of checking new measurement standards of providing a consumer relevant testing, while maintaining repeatability and reproducibility at a reasonable cost level, is well implemented and results have been broadly discussed with stakeholders also. New EU delegated regulations have been published also in December 2019 where some aspects are successfully transferred into already. However, work is ongoing still. Technical Committee CENELEC TC59X was deciding to prepare annual reports for making the progress visible on a broader scale. It is expected that this will foster the activities additionally. Furthermore, the topic anti-circumvention has been more explored in detail in the previous years. Both, consumer relevant testing and anti-circumvention are related to each other and need to be processed close together.

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ANTICSS – Anti-Circumvention of Standards for better market Surveillance – How to avoid losses of potential energy savings caused by circumvention

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Keywords: circumvention; market surveillance; jeopardy; HORIZON 2020; standardisation

Abstract

Whereas reasons for and remedies against non-compliance under EU ecodesign and energy labelling legislation have already been well analysed, the general topic of suspected manipulation of test results or circumvention received a lot of policy attention only recently, not only for car emissions (dieselgate resp. emissionsgate scandal) but also regarding potential negative effects for other legislation. Within the ANTICSS project a definition of 'circumvention' and 'jeopardy effects' with regard to EU Ecodesign and Energy labelling legislation has been developed, and published in 2019, which clearly delimitates the act of circumvention from non-compliant products and other effects.

Based on the ANTICSS definitions of 'circumvention' and 'jeopardy effects', the ANTICSS team of 19 partners from eight countries, coming from research organisations, Energy Agencies, MSAs, test laboratories and NGOs, analysed eight product categories in detail, in order to detect where circumvention may happen, and estimate the magnitude of possible losses of energy savings due to circumvention. Finally, recommendations were derived that will support policy makers and standardisation bodies to prevent future circumvention under EU ecodesign and energy labelling.

Introduction

The European Commission estimates that 10-25% of products put on the EU market do not fully comply with energy efficiency labelling regulations, and around 10% of potential energy savings may be lost due to non-compliance [1]. According to the Special Report 'EU action on ecodesign and energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance' of the European Court of Auditors this would roughly correspond to the final electricity consumption of Sweden and Hungary combined [2]. The reasons for non-compliance include a missing or incorrect energy label, non-compliance with information requirements, as well as incorrect classification of the energy class.

Against this background, the European Union's Horizon 2020 research and innovation programme funded in 2018-2021 the project *ANTICSS – Anti Circumvention of Standards for better market Surveillance* conducted by 19 partners from eight countries, coming from research organisations, Energy Agencies, Market Surveillance Authorities (MSAs), test laboratories, non-profit (NGOs) and consumer organisations. The overall goals and objectives of the ANTICSS project are [3]:

- Avoid energy losses from non-compliance.
- Contribute to the enforcement of EU product legislation and set a clearer policy and enforcement framework.
- Increase confidence among purchasers, manufacturers and retailers.

After a comprehensive assessment of possible suspected cases of circumvention related to EU ecodesign and energy labelling, definitions of circumvention and jeopardy effects were published that clearly delimit circumvention from other effects. [4] Based on these definitions, potential impacts on projected energy savings were estimated, and recommendations for MSAs, EU policy makers, European Standardisation

Organisations, and also manufacturers were derived. This paper presents an overview of where circumvention can happen, estimates the impact of circumvention on potential losses of energy savings, and provides recommendations to facilitate the identification and prevent future circumvention of EU legislation.

Theoretical Background

After the issue of circumvention entered the policy agenda, a specific article on circumvention was introduced in the most recent EU ecodesign regulations on electronic displays, light sources, dishwashers, washing machines, washer-dryers, refrigerating appliances and those with a direct sales function from 2019 onwards as shown in figure 1:

Figure 1. Article on circumvention published in ecodesign regulations from 2019 onwards

Circumvention

The manufacturer, importer or authorised representative shall not place on the market products designed to be able to detect they are being tested (e.g. by recognising the test conditions or test cycle), and to react specifically by automatically altering their performance during the test with the aim of reaching a more favourable level for any of the parameters declared by the manufacturer, importer or authorised representative in the technical documentation or included in any of the documentation provided.

The ANTICSS project considers the recognition of the test situation, and automatical optimization of the performance and/or resource consumption of a product, as published in the above mentioned article as a first way of circumvention. Going beyond this article, the project has revealed two more ways of how circumvention can take place.

ANTICSS understanding and definition of circumvention

The second way of circumvention might be certain pre-settings or manual alterations to the product in order to achieve better results during the test situation. Specific manufacturer's instructions for the preparation and the development of a laboratory test can be necessary, e.g. for safety reasons, and are therefore generally permissible by test standards. However, if such instructions have to be used exclusively by test laboratories and alter the product behaviour to optimise its performance under testing, the ANTICSS project identifies this as circumvention. [3]

A third way of circumvention could be by programming products to provide very good energy efficiency and/or resource consumption for the time in which the conformity verification test is expected, or for a predefined number of cycles. At the time of placing on the market the product is programmed in a way to make it compliant if selected by a MSA for compliance verification but, to automatically change it's performance a certain time after it is put into service. The automatic modification does not take place during the period in which the verification of compliance is expected but only afterwards, for example, to ease performance restrictions imposed by compliance with the regulatory requirements and make the product more attractive to end users in actual use, but also less efficient. The software is already present in the delivered product, i.e. not provided subsequently via software update, as this would be prohibited under the latest ecodesign regulations. [3]

Given this information, the ANTICSS project developed a more comprehensive definition of circumvention, which includes the three possible routes (figure 2) [4]:

Figure 2. ANTICSS definition of circumvention

ANTICSS definition of circumvention
Circumvention is the act of designing a product or prescribing test instructions, leading to an alteration of the behaviour or the properties of the product, specifically in the test situation, in order to reach more favourable results for any of the parameters specified in the relevant delegated or implemented act, or included in any of the documentations provided for the product. The act of circumvention is relevant only under test conditions and can be executed e.g. a) by automatic detection of the test situation and alteration of the product performance and/or resource consumption during test, or b) by pre-set or manual alteration of the product, affecting performance and/or resource consumption during test or c) by pre-set alteration of the performance within a short period after putting the product into service.

In a number of the cases collected by the ANTICSS project the products' behaviour was not clearly attributable to the above definitions of circumvention but was nevertheless still suspicious. Against this background, the ANTICSS project developed the concept of jeopardy effects, i.e. a product behaviour that is not circumvention and thus cannot be claimed non-compliant, but allows a distortion of the test results due to loopholes or other weaknesses in standards or regulations (figure 3). [4]

Figure 3. ANTICSS definition of jeopardy effects

ANTICSS definition of jeopardy effects
Jeopardy effects encompass all aspects of products or test instructions, or interpretation of test results which do not follow the goal of the EU ecodesign and/or energy labelling legislation of setting ecodesign requirements and providing reliable in-formation about the resource consumption and/or performance of a product. These effects may not be classified as circumvention but become possible due to loopholes or other weaknesses in standards or regulations.

Differentiation between general case and tested model

During the onward analysis of cases it became obvious that circumvention can happen in a range of various situations and on different levels. Thus, the project further distinguishes for the categorisation between the general case and the product level (Figure 4). The *case level* represents suspect behaviours initially reported by third parties to the project, for example by a MSAs or other stakeholders. At this level, ANTICSS differentiates between hints for circumvention, and jeopardy effects [3]:

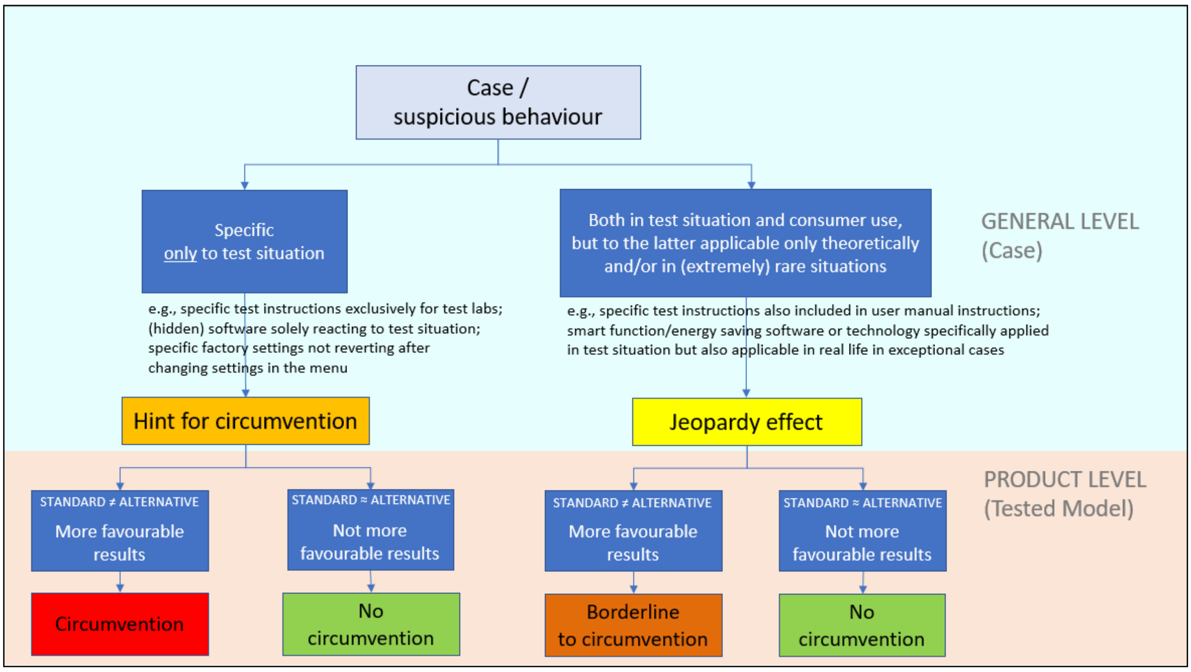
- **Hints for circumvention** (*case level*): *Initially reported cases where the suspect behaviour leads to more favourable results exclusively during the test situation but not during consumers' use in real life. If such act was then proven by laboratory testing in ANCTICSS, the tested model* (*product level) is categorised as* ***circumvention****.*
- **Jeopardy effects** *(case level*): *Initially reported cases where the suspect behaviour occurs both in the test situation and in real-life, but to the latter applicable only theoretically or in* (*extremely*) *rare situations. If such act was then proven by laboratory testing in ANTICSS, the tested model* (*product level*) *is categorised as* ***borderline to circumvention****.*

Examples are specific test instructions also included in the user manual instructions; or energy or resource saving software or technologies which are only applicable in exceptional cases in real life, whereas they are fully considered in the test situation. These acts are not relevant only under test conditions, but nevertheless, the design of the product or the test instructions result in more favourable results especially, but not exclusively, in the test situation. [3]

The *product level* (Figure 4) reflects the final assessment of test results after laboratory testing of selected product models within ANTICCS. For this purpose, ANTICSS used the verification tolerances of the tested parameters as provided in the ecodesign and energy labelling regulations for market surveillance purposes as a reference for determining the significance of the deviation between the results achieved under the standard and the alternative testing conditions. If the deviation exceeded the verification tolerances, the result of the alternative test is considered to be significant and thus worth a specific analysis to understand if this would be a consequence of circumvention or – if initially considered a jeopardy effect – of borderline to circumvention. [5]

For some of the initially reported suspicious cases, the test results of the specific models that were tested within the project resulted as without circumvention. In fact, despite the act of circumvention has not been found in the few models tested in the ANTICSS project, the suspected behaviour might still be considered valid for and replicable by other models of the same product category not tested within ANTICSS, i.e. at case level. [5]

Figure 4. ANTICSS categorisation of cases and tested models. Differentiation between hints for circumvention (in orange), and jeopardy effects (in yellow) for a general level assessment and between circumvention (red), borderline for circumvention (dark orange) and no circumvention (green) on a case level



Methodology

ANTICSS model selection procedure to target circumvention

From the initial 39 cases reported to the ANTICSS project, 21 cases were deemed as non-compliant, compliant or duplicates; for the remaining 18 cases of eight different product categories, classified either as hint for circumvention or jeopardy effect, the test laboratories in the ANTICSS project developed and applied alternative test methods. For each of the selected product categories three models were tested.

The model selection procedure applied within ANTICSS was specifically targeted at finding appliances with a high probability of having a circumvention behaviour. A targeted selection was implemented in those cases where specific brands and/or models had been identified as part of the ANTICSS consultation of stakeholders. Alternatively, when no specific brand/model was referred to in the reported case, a semi-random selection was applied. The main search focus was on the technical features or peculiarities associated with the reported suspected act of circumvention or jeopardy effect. Test laboratories were supporting with their gained experience and know-how to assess these technical features. Lastly, if the previous approaches still did not have delimited the necessary shortlist, other selection criteria based on expert judgement and, if necessary, full randomization were utilised. To avoid unnecessary redundancy, it was taken care that the three different models were not too similar (e.g. variations of the same product model within the same brand), or equivalent (e.g. same model sold under different brand/model names).

ANTICSS impact assessment of circumvention

For the models categorised either as circumvention or borderline to circumvention on the basis of the ANTICSS test results two impact scenarios were calculated:

The realistic circumvention scenario: the minimum and maximum possible losses of potential energy savings are calculated on the basis of the combined knowledge of the market shares of the technical features of the considered appliances, and the estimated market share of the products probably showing the circumvention behaviour coming from experts from Energy Agencies, MSAs, test laboratories or standardisation bodies. In case this information was not available, a conservative market share of 5 % was estimated for the realistic minimum scenario.

The extensive circumvention scenario: the possible losses of potential energy savings are calculated considering all products that have the same technical feature responsible for the identified circumvention behaviour and are thus theoretically prone to the same type of circumvention.

First, the yearly impact of the relevant cases of circumvention or borderline to circumvention was calculated an in a second step, the impact over appliances' lifespan was assessed by using the average operational lifespan of the appliances reported by Wierda et al. [6].

Besides the losses of potential energy savings, the potential additional emission of CO_2 equivalents is calculated by using the conversion factor of 255 g CO_{2eq}/kWh [7].

Formulation of the final ANTICSS recommendations

From the beginning, the ANTICSS project focused its dissemination and awareness raising activities on the target groups that are occupied with the complex topic of circumvention, who are:

- **Market Surveillance Authorities** and **test laboratories** in terms of the verification procedure of product compliance.
- **Policy makers** and **standardisation organisations** with regard to the development and revision of ecodesign and energy labelling regulations and the respective harmonised standards.
- **Manufacturers** designing products and placing them on the market
- **Consumer organisations** and **environmental NGOs** advocating for consumers and the environment.

Furthermore, ANTICSS organised a broad stakeholder consultation, addressing a total of 278 experts at European level (39 MSAs, 61 industry representatives and 178 consumer organisations, test organisations and environmental NGOs to contribute their views and experiences. 39 cases of suspicious behaviour were analysed in detail. [4]

In four dedicated workshops, the perspectives of all stakeholders mentioned above, were considered in the formulation of the final ANTICSS recommendations to better address circumvention in future standardisation and policy processes on ecodesign and energy labelling.

Results and Discussion

Cases of circumvention and borderline to circumvention

Cases of circumvention or borderline to circumvention were identified in different product groups. The six most interesting ANTICSS tests results in terms of circumvention are presented in the following.

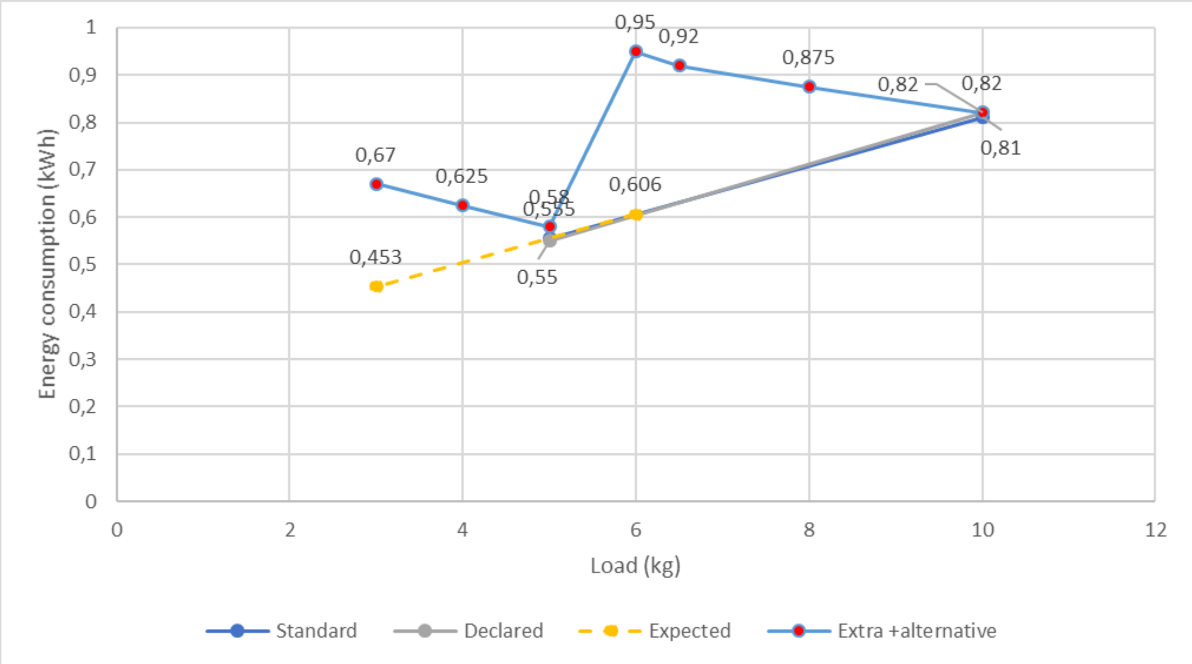
Example 1: Washing machines – specific optimisation at full and half rated capacity

According to the harmonised standard EN 60456:2016, for washing machines a series of seven tests has to be carried out with three different treatments in the standard programmes as follows: Half load: two test runs at treatment 40°C; half load: two test runs at treatment 60°C; and full load: three test runs at treatment 60°C. The suspicion is that washing machines might be optimised in a way to gain more favourable results for the energy and water consumption at the two testing points of full and half load as specified in the harmonized standard, whereas the consumption values follow a different pattern when the machine is run at different loads.

For the ANTICSS alternative testing procedure, the tests according to the treatments above were performed according to EN60456:2016 with a reduced load of 6 kg instead of the full load of 10 kg as declared by the manufacturer and with a half load of 3 kg (instead of 5 kg). The results for one of the three tested models suggested that the washing machine might be optimized specifically for the standard loads. So, the ANTICSS consortium decided to perform additional tests at 4 kg, 6.5 kg and 8 kg at 60°C treatment to better understand the machine's behaviour. The results were striking (see Figure 5):

- The energy consumption values at loads lower than half rated capacity of 5 kg (0.55 kWh) were higher (0.63 kWh at 4 kg and 0.67 kWh at 3 kg) and also the energy consumption values at loads lower than full rated capacity of 10 kg (0.81 kWh) were higher (0.88 kWh at 8 kg, 0.92 kWh at 6.5 kg and 0.95 kWh at 6 kg)
- There was a significant, inexplicable increase of the energy consumption from 0.55 kWh at 5 kg to 0.95 kWh at 6 kg load.

Figure 5. ANTICSS results of a washing machine model: energy consumption of the 60°C standard programme using different loads



The increasing energy consumption at lower loads is remarkable as it could rather be expected that the energy consumption of the washing machine would rise with increasing wash load or getting lower with smaller loads (note: a linear dependency of the washing machine's energy consumption to the load is an approximation introduced by the ANTICSS project for sake of simplicity although it is well known that the relation is not strictly linear). The tested model could be categorized in two different ways:

a) borderline to circumvention, assuming that the more efficient test results for the energy and water consumption at full and half rated capacity (compared to different loads in-between) would also be achieved in real life when consumers load the machine around these capacities.

b) circumvention, imagining that the model could have a sensor that automatically detects the weight of the load, and being programmed in a way that if the weight corresponds to the exact load used in the standard test (full and half load of the rated capacity, standard garments), the energy and the water consumption would be reduced exclusively under these standard test conditions, but not in consumer use.

This case gives strong indications how products whose performance varies with capacity can be optimised towards a legislation setting a reduced number of capacities as representative of the overall product performance.

Example 2: Dishwashers – specific loading instructions

Standard EN 50242:2016 for measuring the performance of electric household dishwashers, states that '*The dishwasher manufacturer's instructions regarding installation and use shall be followed.*' The testing of one dishwasher model following the manufacturer's instructions according to the harmonised standard required the removal or change of the position of many of the accessories that were fitted to the appliance as supplied. Instructions, e.g. removal of a third rack or alteration of relevant parts (e.g. split of cutlery basket into two parts at different positions) were exclusively given in the Instructions for Test Laboratories, not in the user instructions; therefore, this case was categorized as hint for circumvention according to Figure 4.

The ANTICSS alternative testing procedure was conducted according to harmonised standard EN 50242:2016 and manufacturer's instructions but *without* removing or altering the accessories. An alternative loading scheme was designed, fitting to the maximum number of place settings and corresponding serving pieces when the machine was loaded as supplied to the market. With this alternative loading scheme and all accessories kept in place in the machine, only 12 instead of 16 place settings could be fitted into the dishwasher, see Table 1. By this means, the load capacity, i.e. the number of loadable place settings, was reduced by 25%. Although the absolute water consumption did not change and the total energy consumption was slightly lower (-3,2%) compared to the standard test results due to the reduced weight of the load, the specific energy and water consumption per place setting increased by 29% and 34% compared to the standard test results. For consumers, this means that in real-life only 12 instead of 16 place settings could be loaded and sufficiently cleaned, which results in more cycles per year to clean the same amount of dishes, and thus increases their annual energy and water consumption.

Table 1. ANTICSS test results, dishwasher

		Standard test results	ANTICSS alternative test results	Deviation
Standard place settings (ps)		16	12	-25%
Specific energy consumption (Wh/ps)		47.2	60.9	+29%
Specific water consumption (L/ps)		0.68	0.91	+34%
Energy efficiency class		A+++	A+++	No difference

Considering that the manufacturer's instructions regarding a loading scheme are exclusively provided for test institutes, the product is considered to be manually altered, and the resource consumption affected only during the laboratory testing. The deviation of the specific energy and water consumption exceeded the verification tolerances; therefore, the result of the alternative test is considered to be significant and the tested model is categorized as circumvention according to Figure 4. The loading capacity is one of the declared parameters on the Energy Label and thus a purchase criterion for consumers. Since the loading capacity is also used to calculate the energy efficiency index, a higher loading capacity might help reaching a better energy efficiency class, although this was not the case for the specific model tested within ANTICSS.

Example 3: Ovens – volume measurement without shelf guides

Standard EN 60350-1:2016 for measuring the performance of household electric cooking appliances states the following for measuring the volume: '*Removable items specified in the user instructions to be not essential for the operation of the appliance in the manner for which it is intended shall be removed before measurement is carried out.*' In the tested oven model, the user instructions contained one specific recipe for making yogurt, which indicated that it is necessary to remove the accessories and shelves and that the cooking compartment must be empty. Due to this specific recipe in the user instructions, the standard test of the volume had to be done removing all shelf guides. The ANTICSS alternative testing procedure was conducted according to standard conditions of EN 60350-1:2016, except the volume was measured *with* the shelf guides in their position.

In the alternative procedure, the volume with shelf guides included was lower (9 litres or around 13%) than in the standard procedure without the shelf guides, see Table 2. The energy consumption was the same for the standard and the alternative testing. However, the difference in the volume had an impact on the calculated Energy Efficiency Index (EEI), which was 5% higher than under standard test conditions. For the tested model, however, the higher EEI did not result in a change of the energy efficiency class.

Table 2. ANTICSS test results, oven

	Standard test results	ANTICSS alternative test results	Deviation
Volume (L)	71	62	-13%
Energy consumption (kWh/cycle)	0.71	0.71	0%
Energy Efficiency Index	83.5	87.7	+5%
Energy efficiency class	A	A	No difference

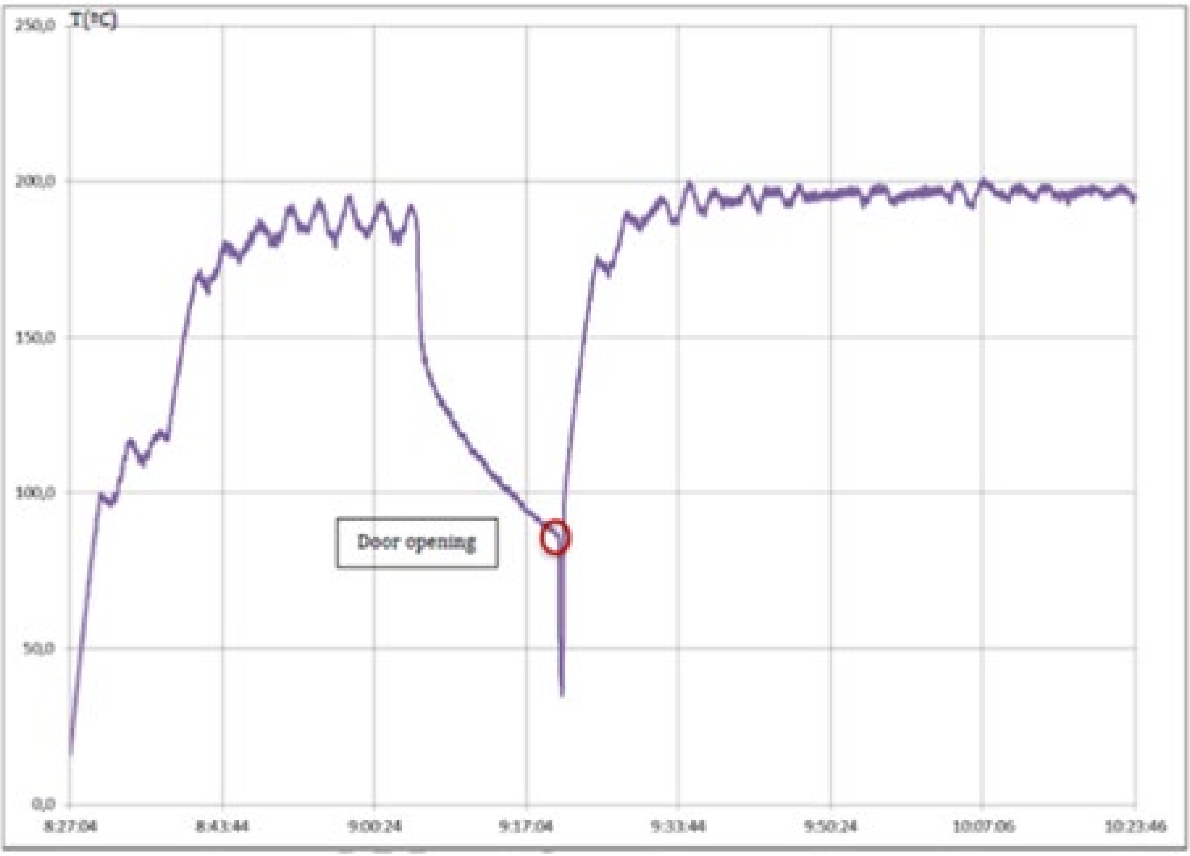
The inclusion of a recipe where the shelf guides are not needed (which is then the setting of the oven for the standard test) was not exclusively provided in the instructions for test laboratories but also included in the user instructions. This provides the possibility of such a setting in consumer use. Nevertheless, the use of an oven without shelf guides seems to be an exceptional use and not the operation of the appliance in the manner for which it is usually intended, so it remains suspected that the inclusion of such a recipe is intended to achieve more favourable results specifically under testing; the case is categorized as jeopardy effect. The deviation of the volume exceeded the verification tolerances, i.e. the result of the alternative test is considered to be significant and the tested model is categorized as borderline to circumvention according to Figure 4. The volume of ovens is one of the declared parameters on the energy label, i.e. purchase criterion for consumers. Since the volume is also used to calculate the Energy Efficiency Index, a higher volume might help reaching a better energy efficiency class, although this was not the case for the specific model tested within ANTICSS.

Example 4: Ovens – automatic temperature reduction function

The first step of the test cycle according to EN 60350-1:2016 for measuring the performance of household electric cooking appliances, the energy consumption measurement, is done with a brick (soaked up with water to simulate a piece of beef) loaded in the centre of the oven. In the second step, a consecutive temperature measurement of the empty oven is done. Between the two steps, the door necessarily has to be opened to remove the brick. To measure the energy consumption of the oven in the first step, a certain temperature-rise as defined in the standard has to be reached in the centre of the brick.

The results of the ANTICSS testing for one tested model is shown in Figure 6. During the first step (energy consumption measurement) in the ECO mode, the temperature in the oven was considerably lower than the targeted temperature setting: the total length of the first step was 54 minutes, but the temperature of the centre of the oven was around the set temperature of 190°C for only approx. 20 minutes. After this, the temperature dropped down to 89°C, whereas the expected and normal behaviour of an oven would be to maintain the temperature of around 190ºC for most of the time. The temperature was only increased again ***after*** the door was opened to remove the brick. In the second step (temperature measurement), the temperature remained stable during the test period.

Figure 6. ANTICSS results of an oven model in ECO mode: energy consumption measurement (step 1) and temperature measurement (step 2)



In a tested non-ECO mode ("fan assisted" mode) of the same model, the temperature in the centre of the oven remained stable for both the energy consumption measurement and the temperature measurement. Also, the second oven model tested in ANTICSS did not show this behaviour: both in ECO and in "Conventional with fan" mode of that model, the temperature in the centre of the oven remained stable for both steps.

It seems that the ECO mode of the first model has been specifically designed to reach lower, i.e. more favourable values for the energy consumption by reducing the temperature while still maintaining the target temperature rise in the centre of the brick. Only *after* the first hour, i.e. usually when the testing duration of the energy measurement is finished, the temperature remained stable at the required temperature setting. Probably the opening (and re-closing) of the oven door in the standard testing, or, alternatively, a certain pre-set period of time, triggered the temperature to increase so that the required temperature value could be reached for the subsequent temperature measurement. The temperature decrease does not apply exclusively during the test situation but occurs always during the first hour, i.e. applicable both in the test situation and during consumer use; thus, the case is categorized as jeopardy effect according to Figure 4. The temperatures of the alternative test are deviating significantly from standard requirements, i.e. the tested model is categorized as borderline to circumvention according to Figure 4.

Example 5: Refrigerating appliances – screen switch-off function

Standard EN IEC 62552:2013 for measuring the performance of household refrigerating appliances states: *'The refrigerating appliance shall be set up as in service in accordance with the manufacturer's instructions.'*

For the tested refrigerating model, the display of a controller, providing a digital clock, is activated each time the door is opened. In case the consumer is away for a longer period, the cabinet can save energy by disabling the display after 24 hours. The appliance does not have a functionality to turn off the display permanently. It only controls whether the display remains always on or is turned off after 24 hours without door opening detection; it is not possible to increase or shorten this time in the settings. The user instructions state to leave the screen switch-off function in the pre-set value (i.e. turn-off after 24 hours without door openings) in order to save energy and in case that the pre-set switch-off function is disabled the energy consumption will slightly increase.

Therefore, the standard test has to be done with the screen switch-off function enabled, i.e. automatic turn-off after 24 hours without door openings. As the harmonized standard does not include any door openings this means that the display will be permanently turned off under standard test conditions, whereas in everyday life, the display will be activated most of the time due to the normal use of the refrigerator with daily door openings.

For the ANTICSS alternative test procedure, the input power of the display was measured separately during an off cycle of the cooling system, while switching the display on and off. The difference of the measured input power (2.1W) was attributed to the display. The annual energy consumption of the appliance was then calculated by adding the energy consumption of the activated display (estimating 20 days of absence per year with the display being deactivated) to the annual energy consumption measured with the harmonised standard.

Table 3. ANTICSS test results, refrigerator

	Standard test results	ANTICSS alternative test results	Deviation
Energy consumption (kWh/year)	169	186	+10.3%
Energy Efficiency Index	20.3	22.4	+10.3%
Energy efficiency class	A+++	A++	1 class

The results in Table 3 show that there would be an additional energy consumption of around 17 kWh/year due to the display, which cannot be switched-off manually. This is an increase of 10.3% compared to the results of the test with the harmonised standard conditions. The energy efficiency class would change from an A+++ to A++.

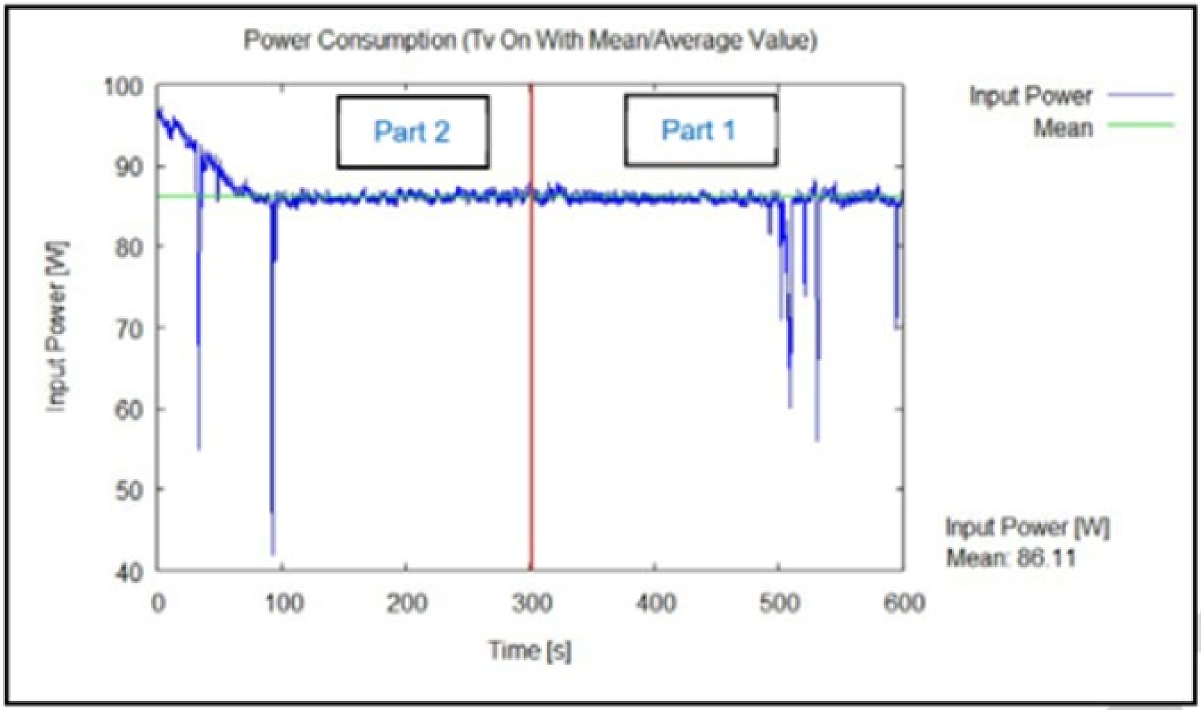
During the standard testing the appliance operates as if the consumer is not at home and deactivates the display to save energy. Thus, the measured and declared energy consumption of the standard test represents the most efficient mode of the appliance, which is not providing a reliable value about the actual energy consumption during real use. The turn-off of the display does not apply exclusively during the test situation but occurs also during consumer use, e.g. when the consumer is absent for a holiday period; thus, the case is categorized as jeopardy effect. The deviation of the energy consumption of the tested model exceeded the verification tolerances, i.e. the result of the alternative test is considered to be significant and the tested model is categorized as borderline to circumvention according to Figure 4.

Example 6: Televisions – automatic backlight reduction function

It is well known that the test video to be used for the standard measurement according to IEC 62087-2:2015 for the determination of the power consumption of audio, video, and related equipment such as televisions includes hard cuts every few seconds, i.e. fast moving images which are very different from the characteristics of average broadcast content. This might facilitate the device recognizing this sequence as a test video and implementing special functions to reduce for example the luminance (backlight or OLED) during this loop to decrease the power consumption specifically in the test situation.

For one of the three models tested in ANTICSS, the results according to the harmonized standard showed that the model indeed has a special function to detect fast changing content: the backlight (finally the input power) was reduced step by step starting at about 95 W at the start of the test video and settling down at about 85 W after 100 seconds for the rest of the 10 minutes test sequence (see Figure 7). Two other models tested in ANTICSS did not have such a backlight reduction function.

Figure 7. ANTICSS results of alternative testing of a TV model using an automatic back-light reduction function



This could be either classified as jeopardy effect (following the manufacturer's explanation that the function is also applicable to any content in real life that entails rapid scene changes and/or depicting a large amount of motion such as sports programmes), or as hint for circumvention (based on the experience of the test lab that such fast moving pictures never apply in real-life, i.e. the software exclusively reacts to the specific fast-moving images of the standard test video – which however could not be proven in ANTICSS).

In principle, such a backlight reduction function can be used to gain more favourable results of the declared parameters. However, for the specific model tested in ANTICSS this was not exploited – on the contrary: the *declared* values for the on-mode and annual power consumption were significantly higher, i.e. 23% worse than the results of the standard measurement, even resulting in a declared lower energy efficiency class A instead of A+ as measured, see Table 4. According to the manufacturer, this over-declaration is a safety margin due to variations between units resulting of the construction process, i.e. to ensure all units being compliant when tested by Market Surveillance Authorities.

Table 4. ANTICSS test results, television model

	Standard test results	Declared	Deviation
On-mode power consumption (W)	85	110	-23%
Annual power consumption (kWh/year)	118	153	-23%
Energy efficiency class	A+	A	1 class

The specific model tested in ANTICSS is not categorized as circumvention according to Figure 4. However, the use of a backlight reduction function to gain more favourable results of the declared parameters can still be considered potentially applicable to other models of the product category not yet tested.

Possible impacts of circumvention and jeopardy effects

The ANTICSS impact assessment revealed possible losses of energy savings for only some of the reported cases of circumvention or borderline to circumvention. Not for all cases, the quantification of potential losses was possible. Table 5 shows the total annual losses of potential primary energy savings and the corresponding additional emissions of CO_{2eq}, if circumvention or borderline to circumvention, as found in ANTICSS, occurs during appliance testing. The possible losses are presented in TJ per year in the realistic minimum and maximum scenario. For the extensive scenario the possible losses are shown per year, and also over the average operational life span of the product. The calculations take into account the potential loss per product and the number of appliances expected to be sold in the year 2020. The calculations are based on the assumed market share of appliances that might show this behaviour. These shares are presented in brackets.

Table 5. Total annual impacts due to circumvention or borderline to circumvention

Case	**Realistic circumvention scenario [TJ]**		**Extensive circumvention scenario [TJ]**	**Extensive circumvention scenario over appliances' lifespan [TJ]**	**Average operational lifespan of appliances [years]**
	minimum	maximum			
Television: automatic backlight reduction function	**197** *(5%)**	**691** *(17,5%)*	**3,946** *(100%)*	39,459	10
Washing machines: specific optimisation at full and half rated capacity	**41** *(5%)*	**328** *(40%)*	**819** *(100%)*	12,289	15
Refrigerating appliances: sceen switch-off function	**52** *(2%)*	**325** *(12,5%)*	**651** *(25%)*	10,411	16
Dishwashers: specific loading instructions	**88** *(2%)*	**178** *(4%)*	**333** *(9%)*	5,001	15
Ovens: volume measurement without shelf guides	**17** *(5%)*	**232** *(70%)*	**232** *(70%)*	4,417	19
Total possible annual losses of potential primary energy savings [TJ/year]	**395**	**1,754**	**5,982**	**71,577**	
Additional emissions CO_{2eq} [TJ/year]	**13,336**	**59,167**	**201,766**	**2,414,319**	

**Figures presented in brackets show the assumed market share of appliances that might show this behaviour*

According to the ANTICSS impact assessment about 395 to 1,754 TJ (realistic minimum and maximum scenario) or 5,982 TJ (extensive scenario) of primary energy savings could be lost per year due to acts of circumvention or borderline to circumvention of the considered product categories, corresponding to a range of 13,300 to almost 201,800 tons of CO_{2eq} per year. Over the average operational lifespans of the appliances, the potential primary energy losses could amount up to nearly 71,577 TJ/year in the extensive circumvention scenario, corresponding to up to roughly 2,4 Mio tons of additional CO_{2eq} emissions. These CO_{2eq} emissions are equal to the emissions from a middle class car (120g CO_{2eq}/ km [8]) surrounding the globe 42,000 times (1,700 Mio km).

The ANTICSS results show that not only the electricity consumption but, also other performance parameters might be optimised for the standard test, i.e., the water consumption of washing machines or dishwashers or the functional performance of the appliance might be affected. When noticed by the consumer, a non-satisfactory performance under real-life conditions might lead the consumer to switch to other, more performing but, also probably more resource-intensive programmes. In addition to the losses of potential energy savings, the trust of the civil society and the business operators in ecodesign and energy labelling and standards, which are key EU policy instruments, might be damaged. Thus, further severe impacts of circumvention might be: market distortion and unfair competition; loss of reputation for individual manufacturers, respectively entire industries; loss of consumers' and businesses' trust in the overall effectiveness of European legislation and standards.

ANTICSS recommendations for policy makers and standardisation organisations

Circumvention is considered an illegal act according to a new Article 6 included in a number of recent product specific ecodesign regulations adopted in 2019. A generic prohibition is also present in Article 3.5 of the energy labelling framework regulation 2017/1369. However, this prohibition only covers products which recognise the test conditions and react by automatically altering their performance during the test. Another weakness of the legislation is the obligation to follow manufacturer's instruction for the installation of a product, or its setting before laboratory testing. As the manufacturer is the only legally responsible for the characteristics and compliance of a product, the advice is correct and unavoidable. However, the misuse of manufacturer's instructions, i.e. prescribing instructions for a specific set-up in order to achieve more favourable results, should be tackled in the standards and in the legislation. When products or respective test settings have been manipulated with the aim of circumvention, these products appear to comply with the legislation requirements when tested following the measurement methods of the harmonised standard. Therefore, it is impossible to detect circumvention with the current harmonised standards. The practice has shown that some time is needed after the application of a new regulation or standard to understand the actual implications and relations among the different legal requirements and test conditions. Thus, loopholes and weaknesses in the existing ecodesign and energy labelling legislation and the respective harmonised standards can be exploited by the manufacturers to achieve more favourable results. Considering the above mentioned aspects, the following recommendations can be made to help policy makers and standardisation organisations to avoid future acts of circumvention:

- Extend the legal definition of circumvention in ecodesign and energy labelling regulations to cover all types of circumvention.
- Specify in harmonised standards the instructions manufacturers may provide only for laboratory testing to avoid misuse.
- Make possible the use of modified measurement methods aimed at indicating the possible presence of circumvention.
- Analyse the application of legislation at regular intervals to identify and overcome jeopardy effects, loopholes and other weaknesses that might facilitate circumvention.

ANTICSS recommendation for Market Surveillance Authorities and test laboratories

Due to the current legal framework, the action of MSAs to detect different possible acts of circumvention is currently still limited. However, the collection of such cases and exchange of experiences among MSAs and test laboratories can make a relevant contribution to avoid future circumvention. Following only the current harmonised standards during laboratory testing, is not sufficient to detect acts of circumvention. Modified test methods are necessary to identify circumvention in the test situation. MSAs can provide details on the suspect behaviour and help to develop these methods, while test laboratories are well-experienced in the measurement conditions for the different product parameters. Thus, the close cooperation between MSAs and test laboratories, and the involvement of MSAs in ecodesign and energy labelling regulatory processes is advisable. Therefore, the following recommendations can be made to strengthen the competence regarding circumvention of MSAs and test laboratories:

- Identify possible circumvention and jeopardy effects during the compliance verification and laboratory testing of investigated products.
- Support the development and application of modified measurement methods to identify circumvention.
- Regularly exchange experiences about suspicious cases.

- Bring your expertise in the legislation and standardisation processes.

The responsibility of industry and product manufacturers

Circumvention is an illegal act. In this respect, the task and responsibility of manufacturers is to design products that comply with the applicable EU legislation. More favourable results due to the exploitation of weaknesses and loopholes in legislation are currently not considered as non-compliance, but are against the spirit and the goals of EU ecodesign and energy labelling legislation. Manufacturers can help to better achieve the goals of EU ecodesign and energy labelling legislation by uncovering acts of circumvention, and closing ambiguities or loopholes in legislation and standards. Manufacturers know the products on the market and could therefore recognise, and should report at an early stage, any apparent irregularity or suspect case to MSAs. In addition, individual manufacturers or their industry associations are members of the ecodesign and energy labelling Consultation Forum, and thus actively involved in the development and revision of regulations and standards. In order to overcome loopholes or ambiguities in legislation and standards, they should add their technical expertise and knowledge to the development and revision process of legislation or standards.

Conclusions

Within the ANTICSS project, a team of experts from research organisations, MSAs, test laboratories, industry representatives, consumer and environmental NGOs contributed their views and experiences in terms of circumvention. Eight product categories were analysed in detail, in order to detect where and how circumvention may happen, and estimate the magnitude of possible losses of energy savings due to circumvention. The results show that circumvention can take place in different product groups, and has a severe impact not only in terms of environmental, resource consuming aspects but, also in terms of the trust of the civil society and business operators in ecodesign and energy labelling and standards, the key EU policy instruments.

The project has highlighted that the existing ecodesign and energy labelling legislation, and the harmonised standards include loopholes, ambiguities and other weaknesses that can be exploited by manufacturers in order to achieve more favourable results for their products. The current situation does not allow MSAs and test laboratories to detect circumvention, when following the test procedures of the harmonised standards only. Thus, one of the main outcomes of the ANTICSS project is the development of alternative test procedures that enable MSAs and test laboratories to better identify manipulated products.

The cooperation of the different stakeholders in the ANTICSS project provides a rather comprehensive picture of where and how circumvention can happen. It revealed that some time is needed after the application of a new regulation or standard to understand the actual implications and relations among the different legal requirements and test conditions. Thus, regulation and standards should regularly be analysed in order to detect loopholes and other weaknesses that might facilitate circumvention. The work in ANTICSS has shown that circumvention is a complex subject that can only successfully be handled when all stakeholders bring in their specific expertise. Therefore, it is highly advisable to establish a communication or collaboration platform – engaging all relevant stakeholders such as European Commission, Market Surveillance Authorities, European Standardisation Organisations, test laboratories, industry and NGOs – to exchange experiences and discuss the challenges and conclusions related to circumvention.

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Guidelines for Anti-circumvention in *S*tandards supporting EU Ecodesign and Energy labelling Regulations

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Abstract

The topic of manipulated measurement results also referred to as 'circumvention', has recently received considerable public and media attention, not only for car emissions (e.g. diesel-gate), but also concerning other EU legislation. 'Circumvention' is mostly seen as hiding, cheating, deceptive and usually illegal practices. It can result in increased energy consumption or release of pollutants, all in all, in economic, societal and environmental damage. This issue is highly relevant as the detection and/or avoidance of circumvention contributes to achieving targeted reductions of electricity and resource consumption. Experience has shown that some measurement standards could be affected by 'circumvention' as they can be used to allow deviations or interpretations of the test methods described. Although measurement standards are just one part of broader aspects of 'circumvention', they play a fundamental role in enabling the implementation of the Ecodesign and Energy labelling policy in Europe.

Circumvention during product testing according to European harmonised standards can take place in a variety of forms. The examples gathered on this issue should serve for internal reflection and consequent action within Technical Committees for these situations to be corrected. While those examples are not yet proven to be 'circumvention' according to the Ecodesign and Energy labelling regulations, they are certainly suspicious cases.

With the objective of providing clarity on all those suspicious cases, the Guidelines are being developed which will provide recommendations for product experts writing standards on how to detect and avoid Ecodesign and Energy Labelling test methods being misused for circumvention.

Background

European Standards are essential complementing tools to EU legislation, supporting, among others, the Ecodesign and the Energy Labelling Regulations in providing methods to measure and assess whether products comply with regulatory requirements.

Following specific requests – called 'standardization requests' or 'mandates' from the European Commission, CEN and CENELEC develop ad hoc measurement methods for each regulated product group. The standards containing the measurement methods are then offered for citation in the Official Journal of the European Union (OJEU) and when cited, manufacturers may use them for the conformity assessment of their product concerning the requirements of the concerned regulations.

About 25 CEN and CENELEC Technical Committees develop European Standards in the field of Ecodesign and Energy Labelling, and their number is likely to increase over time depending on the regulatory developments at the level of the European Commission.

These guidelines were developed and approved by the CEN-CENELEC Ecodesign Coordination Group (ECO-CG). This group serves as a focal point concerning standardisation issues relating to the Ecodesign Standardisation Requests delivered under Directive 2009/125/EC on Ecodesign of energy-related products and Regulation (EU) 2017/1369 on Energy Labelling of energy-related products and their future versions. Although the responsibility of ECO-CG is on overseeing European Ecodesign and Energy labelling-related standardisation only, this document may be helpful for other standardisation work too. This document is not published as a CEN-CENELEC Guide. The purpose of these guidelines is "To provide guidance and support to standardisers on Ecodesign and Energy labelling for a systematic consideration of the issue of circumvention in the development of standards". The objective is therefore to raise awareness within the relevant standardisation Technical Committees and their working groups by providing examples of circumvention cases and giving recommendations on how possibilities of circumvention can be reduced or minimised when developing measurement standards.

Introduction

These Guidelines for Ecodesign and Energy labelling should be considered in close relation to the draft "Guide to securing the credibility of IEC publications containing environmentally relevant provisions" developed by ACEA, the Advisory Committee on Environmental Aspects of IEC, which is recommended as a normative reference for ECO-CG. However, while the ACEA guide covers all standards within IEC, the Guidelines laid out here target products under the Ecodesign and Energy labelling regulations of the EU and therefore are more specific to those standards.

Circumvention - Relevance of addressing circumvention

The topic of manipulated testing results or 'circumvention' has received a lot of public and media attention, not only for car emissions ('Dieselgate'), but also with regard to other EU legislation. 'Circumvention' is mostly seen as cheating, deceptive and is usually illegal. It can result in increased energy consumption or release of pollutants leading to economic, societal and environmental damage. This topic is highly relevant as detection and/or avoidance of circumvention contributes to achieving targeted reductions of electricity and resource consumption for product groups covered by EU Ecodesign and Energy labelling legislation. The overall trust of consumers, economic partners and society in the reliability and effectiveness of EU legislation and its underpinning test methods will be strengthened if circumvention is avoided. Overall measures to detect and eliminate circumvention are highly important to prevent the market moving to circumvention practices. In addition to the principles to be applied when drafting standards, further action by other market actors is also necessary. For instance, detection and penalisation of circumvention by market surveillance authorities will be key in preventing such strategies. Furthermore, this also supports fair competition in the market and thus is in the interest of all market actors.

Experience has shown that measurement standards are affected by 'circumvention' as they could be used to enable deviations or interpretations of the measurement method laid down in the standard. Whilst measurement standards are just one part of the broader aspect of 'circumvention', they play a fundamental role in enabling the implementation of the Ecodesign and Energy labelling policy.

Circumvention definitions

'Circumvention' is a term interpreted and defined differently by different actors such as policy makers, standardisation bodies, market surveillance authorities, journalists, civil society, etc. Due to the fact that everyone in this field has their own experience and expectation of what should be allowed or respected, what should not be used or forbidden, it would be an endless discussion to find a commonly agreed definition of what 'circumvention' is.

Therefore, these Guidelines present definitions used to characterise 'circumvention' by relevant actors to show how broad and divergent views or requirements can be. ALL are worth being considered when writing measurement standards for Ecodesign and Energy labelling, although from a legal point of view the definition used in the relevant regulation prevails.

Circumvention - EU regulations and Standardisation Requests

Circumvention is currently addressed within different legislative texts under the Ecodesign and Energy labelling framework:

Energy labelling Framework Regulation (EU) 2017/1369:

The revised Energy Labelling Framework Regulation (EU) 2017/1369 [24] explicitly mentions that methods and standards should deter intentional and unintentional circumvention. It prohibits the inclusion of software or hardware that automatically alters the performance of a product in test conditions (see Recital (35) and Article 3).

Product-specific Energy labelling delegated acts:

Energy labelling regulations for several product categories adopted in 2019 and amended by the omnibus amendments in 2021, explicitly mention circumvention as part of the verification annex for market surveillance purposes. It is stated that where a model has been designed to be able to detect it is being tested (e.g. by recognising the test conditions or test cycle) and to react specifically by automatically altering its performance during test with the objective of reaching a more favourable level of any of the parameters specified in the specific delegated act, the model and all equivalent models shall be considered not compliant.

Product-specific Ecodesign implementing acts:

Similarly to the approach of addressing circumvention systematically under the latest Energy Labelling delegated acts, the Ecodesign implementing acts adopted in 2019 and amended by the omnibus amendments in 2021 also explicitly refer to circumvention. The implementing acts include a specific article on circumvention and on software updates aimed at preventing products that automatically alter their performance in test conditions to improve their declared parameters from being placed on the market. And they refer to this as non-compliance in the verification annex.

Standardisation Requests mandating deliverables to support Ecodesign and Energy labelling:

Furthermore, the Standardisation Requests from the European Commission that mandate the European Standardisation Organisations with the development of standardisation deliverables to support the implementation of Ecodesign and Energy labelling regulations, include generic statements on circumvention to guide those developing standards. Recent Standardisation Requests require that standards set out test procedures aimed at minimising the risk of the performance of a model being automatically altered in test conditions to achieve the objective of reaching a more favourable level of performance.

Circumvention - ANTICSS definition and delimitation to other effects

The European Union's Horizon 2020 research and innovation programme funded project 'ANTICSS –Anti-Circumvention of Standards for better market Surveillance' [1] has as overall objective to assess and clearly define 'circumvention' in relation to EU Ecodesign and Energy labelling legislation and relevant harmonised standards.

By analysing "suspect" product cases the ANTICSS project team developed the following definitions of circumvention as well as jeopardy effects:

- Circumvention is the act of designing a product or prescribing test instructions, leading to an alteration of the behaviour or the properties of the product specifically in the test situation in order to reach more favourable results for any of the parameters specified in the relevant delegated or implemented act, or included in any of the documentations provided for the product. The act of circumvention is relevant only under test conditions and can be executed e.g.,

a) by automatic detection of the test situation and alteration of the product performance and/or resource consumption during test, or

b) by pre-set or manual alteration of the product, affecting performance and/or resource consumption during test, or

c) by pre-set alteration of the performance within a short period after putting the product into service.

- Jeopardy effects encompass all other design aspects of products or test instructions, or interpretation of test results which do not follow the goal of the EU ecodesign and/or labelling legislation of setting ecodesign requirements and providing reliable information about the resource consumption and/or performance of a product. These effects may be not classified as circumvention, but become possible due to loopholes or other weaknesses in standards or regulations.

The definition of 'circumvention' by ANTICSS enlarges the ways in which 'circumvention' can happen: from detection of being in a test situation, by pre-set or manual alteration of the product during test and by pre-set alteration of the performance within a short period after putting the product into service. Jeopardy effects encompass all subject cases which do not follow the goal of the EU ecodesign and/or labelling legislation.

Circumvention and jeopardy effects enable a product to evade appearing non-compliant during testing. Products appear to comply with all the requirements and conditions but the test results are specifically influenced by the use of circumvention behaviour or by the exploitation of any weaknesses or loopholes in standards and legislation to give a more favourable result for the manufacturer. ANTICSS has proposed a decision tree to guide on the categorisation of the different suspicious behaviours discriminating between the hints for circumvention and the jeopardy effects.

The potential relationship between circumvention and so called 'smart' products with specific embedded software has also been analysed by the project.

The ANTICSS project has learned from suspected cases of circumvention through literature research, dedicated expert interviews and practical testing, as well as analysing existing EU Ecodesign and Energy labelling legislation and standardisation, that it is not easy to come to a common view on what is circumvention and what is not.

Circumvention - Definition from IEC / ACEA "Guide to securing the credibility of IEC publications with environmental provisions"

International Standards and other types of standardisation publications are expected to provide commonly agreed, objective and unbiased test methods to determine, amongst others, certain performance aspects of a product or system, such as CO2 emissions or energy consumption. For an IEC publication to be credible, it needs to ensure that its provisions contain test methods that are representative of how the product is used in real-life and/or that the sample under test is representative for the product and prevent, as far as practicable, circumvention [see 30]. This ACEA Guide (available as draft in IEC Administrative Circular AC/28/2020 [22]) contains principles, requirements and guidance so that IEC publications contain credible environmentally relevant test provisions. This Guide is addressed to those who write IEC publications that contain provisions that are assessed by test and that pose a direct or indirect impact on the environment – called 'environmentally relevant test provisions'. It covers test provisions in relation to the operation of a single product or a system of products.

The ACEA Guide provides the following definition:

- Circumvention: activity that results in an advantageous and invalid outcome to an assessment

This definition clarifies that the lack of validity in the assessment outcome could be due to an intentional or an unintentional act, either of which go around the provisions of a standard, a policy or legislation. Another clarification says that the assessment is presumed to be made to a good, service or system. Consequently, if the assessment is deemed to be advantageous, it benefits the provider of the good, service or system.

Additional to the classical measurement principles (repeatability, reproducibility, accuracy of the measurement and the cost of performing the test) and periodic review and timely maintenance, IEC / ACEA proposes representativeness and anti-circumvention as key principles for a test provision of an international standardization publications be considered credible.

Representativeness is defined as the degree to which the assessment of a parameter reflects the population of interest. Such an assessment, following the procedures defined in a standard, should result in an unbiased estimate of those obtained in practice by users of that product. This includes considerations on e.g. geographical, time period, technology coverage, manufacturing deviations of the sample to be tested and use of reference materials in analytical testing.

Products, which show high deviations during manufacturing compared to their specification, could impact representativeness.

To guarantee the representativeness of analytical testing of substances or materials, standard reference substances/materials are necessary. The use of certified reference materials will enhance the representativeness and reliability of the tests.

Note: Certified reference materials are 'controls' or standards used to confirm the quality and metrological traceability of products, to validate analytical measurement methods, or for the calibration of instruments. A certified reference material is a particular form of measurement standard.

Representativeness includes considerations that product technologies, measurement equipment, measurement techniques and end-user expectations can change more swiftly than the usual review cycle of IEC publications. Hence, representativeness requires the technical committees to periodically monitor all these factors and, as needed, revise the test procedures. To monitor changes in end-user expectations committees can review studies conducted world-wide on actual use and performance of products.

Anti-circumvention targets the obstruction of circumvention by openly addressing and minimising risks of misusing test procedures. This refers to any considerations when designing a test method, including predicting, and avoiding the possibility for circumvention. To ensure a credible environmentally relevant test provision it is necessary to minimise the risk of circumvention.

Circumvention can, in theory according to ACEA, be distinguished between active and passive circumvention:

– active circumvention: acts of avoiding a difficulty to conform with an obligation or rule;

– passive circumvention: accidental bypassing conformance with an obligation or rule.

However, in practice, it is oftentimes not possible to clearly distinguish between active and passive circumvention.

In particular in relation to circumvention, the IEC / ACEA Guide proposes a systematic approach for developing standardization publications with credible environmentally relevant test provisions by including requirements on minimisation of the risk for circumvention:

For the purpose of minimising the risk of circumvention in relation to environmentally relevant provisions, writers of IEC publications shall openly address, identify and minimise the risks for test procedures to be misused. Therefore, the possibility for circumvention, in relation to product features, user behaviour, ambient conditions and operating conditions shall be carefully considered.

Writers of IEC publications shall:

– avoid drafting test provisions that can yield unacceptable risk of being circumvented by providing clear provisions and test objectives (avoid room for (miss-) interpretation or the possibility to optimize the behaviour of the test unit under test conditions);

– check and prevent that changes in settings of the test provision would result in overly (dis-) advantageous changes of the test result (sensitivity);

– assess the possibility for hardware or software to be misused (defeat mechanisms) and if relevant include warnings in test provisions against the use of hardware or software as defeat mechanisms;

– repeat the above periodically, in line with the requirements on representativeness.

Often, defeat mechanisms become known only after a test provision has been established, e.g. when technology has changed. Writers of IEC publications shall take this knowledge into account when revising environmentally relevant test provisions." [22]

Circumvention in standardisation supporting Ecodesign and Energy labelling

Circumvention during product testing according to harmonised standards can take place in a great variety of manners. Examples outlined in more detail in the Annex serve for internal reflection for Technical Committees and Working Groups in order to correct such situations should they also apply to the standards they draft. Those examples are not proven to be 'circumvention' according to the Ecodesign and Energy labelling regulations but are suspicious cases that need to be carefully addressed by standardisers in order to close loopholes and weaknesses.

Among the cases outlined in Annex, several examples show how the manufacturers' instruction manual or separate test instructions could be used to gain unfair benefits. This can be by requesting for special accessories to be installed (e.g. bowl support for dishwasher) or removed (e.g. shelf guides in oven) during testing, or by setting a special preparation of the product before testing (e.g. condensation measurement for tumble dryer). When the measurement standard instructs to 'follow the manufacturer instructions', that instruction needs to be followed. Another type of suspicious behaviour is reported where a product is requested to be tested 'out of the box', in particular, when the results measured cannot be reproduced in a later measurement (e.g. factory setting of TV). Other examples stress the consumer relevance of the testing procedure (e.g. using fast moving images in testing TV) or allowing testing under extremely unlikely consumer conditions (e.g. refrigerator without door opening). Furthermore, suspect behaviour of a product has also been identified when testing is performed in special conditions which are designed (almost) only for the purpose of a measurement for Ecodesign and Energy labelling Regulations (e.g. ECO programme in dishwasher, washing machine, oven and other products). In addition, verification tolerances and measurement tolerances and uncertainties have in the past been another area of misuse though these have been largely outlawed through the introduction of Commission Delegated Regulation (EU) 2017/254.

However, it is possible that not all of the reported suspect cases in Annex could be completely prevented as standardised measurement procedures usually have to fulfil other requirements too, e.g. being repeatable, reproducible, consumer relevant and affordable. This is rather similar to the approach to create consumer relevant testing procedures, as also there sometimes repeatability, reproducibility and affordability are prioritised over representativeness [1]. The overall goals must therefore be to develop measurement standards which are well balanced in all relevant aspects. The new task was therefore to develop guidelines for those people writing standards which can help them to avoid that the measurement standards can be used to circumvent provisions regulated in EU Ecodesign and Energy labelling regulations. This is primarily done by providing examples of suspicious cases of circumvention including results of testing (see Annex and references there) to foster the learning between product categories. Secondarily, some guiding principles for writing measurement standards are presented hereafter which try to summarise the most important learning for the different classes of circumvention. Concrete actions to avoid measurement standard to be used for circumvention, however, are omitted as they at first need to be verified internally within ECO-CG. Nevertheless, as similar tasks may exist for other regulations, the basis of those guidelines shall be published globally to allow a general discussion on possible anti-circumvention actions.

Guiding principles for standardisation

Detection of being in test situation

Alteration of the product performance and/or resource consumption during test by detection of the test situation that results in a product being non-compliant is forbidden according to the Energy Labelling framework regulation 2017/1369 and recent Ecodesign implementing acts. However, there are situations where a product detects being in a test situation by default. Examples of this could be products where the programme which is executed during the performance and consumption test is explicitly defined and requested to be included in the Regulation (e.g. dishwashers' ECO-programme). Other examples are TVs tested using a video with fast moving pictures. Products that are optimised under those conditions can hardly be challenged, as they are doing what is requested in the Regulation. What may be challenged are products that are optimised only under those conditions (and not for more typical usage situations).

In addition, products that use detection of their situation can also not be challenged, as such 'smart' operation often can help the product perform a better job or reduce consumption values or even both. What may be challenged are products where automatisms are not disclosed, and the user is not informed about the pros and cons and cannot control the resource consumption and performance of the device.

Alteration of the product performance and/or resource consumption during test by detection of the test situation are likely to happen if different parameters of Ecodesign and/or Energy labelling of a product are measured in different product states (e.g. washing programmes) and/or in separate measurement processes (e.g. separate cleaning and drying measurement in dishwashers). In those cases, manufacturers will almost be forced to optimise the product for those separate measurements independently. But in real use, those pure conditions will almost never apply.

Avoid pre-set or manual alteration of the product in test situation

In some cases, it may be necessary to bring a product into a specific situation to allow a repeatable and reproducible measurement of some provisions. Examples are the loading plan for a dishwasher which specifies in detail where which of the standardised dish items should be placed. Without this loading plan, results would never be reproducible between different laboratories or operators.

However, the alteration of the product may be misused to bring the product into a state which is no longer representative of real usage by the end-user, or not even worst-case real usage conditions. Alterations of the product which are just foreseen under test should not be allowed (such as accessories in a dishwasher used for testing purposes only).

Alteration of the performance within a short period after putting the product into service

In Directive 2009/125/EC, the Commission sets Ecodesign requirements for energy-related products that account for significant volumes of sales and trade in the Union and which have a significant environmental impact and present significant potential for improvement through design, without entailing excessive costs. Those products should maintain their (improved) performance not only when placed on the market but for the foreseeable time of being used or installed. This stays valid, although a certain level of deterioration or wear may be expected as (almost) unavoidable. However, within the legally guaranteed warranty time of a product, its performance and efficiency should be expected to be maintained at much the same level as it was when the product was put on the market. If this principle is agreed, there is no need in the measurement standards to define that testing has to happen (or is possible only) with brand new products. This will also limit the possibility that new products take advantage of the virginity of components.

General recommendations

It may not be at all obvious to persons not involved in the actual standardisation process why specific test conditions or processes have been chosen. Adding a justification for selecting specific conditions for testing may support the understanding and thus the general acceptance of the measurement standard. This is especially necessary when testing conditions are in contradiction to the conditions in which this product is used by the end-user.

Justifications may be especially based on the repeatability and reproducibility of the measurement method and the costs of the measurement. References explaining that these points have been studied and verified would increase understanding of the reasons for the chosen approach and lead to higher trust in the standard as written.

Those justifications may be added as a note in the standard or a separate informative chapter/Annex or in a technical report associated with the standard. Those justifications should be concise in the standard but may cross-reference other sources for more detail.

IEC offers the possibility to publish a "Commented version" of an International Standard. This Commented Version is the only deliverable where the consensus-based content of a publication is enriched with technical information. It is made of a redline version with highlighted areas where Technical Committee experts provide the reasons and rationale for the most relevant changes. The summary of comments is also provided at the end of the document.

With commented versions, users can better understand the rationale for changes made to the newest edition of the standard. Comments include an explanation for the changes as well as information on the impact of these changes on the application and usability of the standard.

Summary and conclusions

This document was developed and approved by the CEN-CENELEC Ecodesign Coordination Group (ECO-CG). Its purpose is to raise awareness within the standardisation Technical Committees responsible for Ecodesign and Energy labelling standards by providing examples of circumvention cases and giving recommendations on how possibilities of circumvention can be deterred or minimised when developing measurement standards.

Circumvention is a term interpreted and defined in various ways by policy makers, standardisation bodies, market surveillance authorities, civil society, etc. Well known and put simply is the core definition from the IEC / ACEA "Guide to securing the credibility of IEC publications with environmental provisions" that Circumvention is an activity that results in an advantageous and invalid outcome to an assessment!

From an EU legal perspective, the description of circumvention used in the relevant regulations will certainly apply. For example, the revised Energy labelling Framework Regulation (EU) 2017/1369 explicitly mentions that methods and standards should deter intentional and unintentional circumvention and it prohibits the inclusion of software or hardware that automatically alters the performance of a product in test conditions.

The topic of manipulated testing results or 'circumvention' has received a lot of media attention e.g. the 'Dieselgate' car emissions scandal. Similar such manipulations have been observed in other product sectors too. 'Circumvention' is regarded to be cheating, deceptive and is usually illegal. It can result in increased energy consumption and release of pollutants with resultant economic, societal and environmental damage. This topic is highly relevant for standards developers as detection and/or avoidance of circumvention contributes to achieving targeted savings of electricity and resource consumption for product groups covered by EU Ecodesign and Energy labelling regulations.

Circumvention during product testing according to harmonised standards can take place in a variety of manners. These can be unwittingly aided by the provisions of the test standard itself.

For example, some frost-free refrigerator-freezers are programmed with a cool-down function. Its purpose being to minimize the temperature increase on the frozen food when the defrost function is activated. These types of refrigerator-freezers have been known to be designed so that the cool-down started just after the maximum testing time specified by the then applicable EN 62552:2013 thus resulting in the extra energy consumption of this function not being incorporated into the test result. Standardizers developing the revised standard, EN 62552:2020, have introduced requirements to eliminate this "work-round". Results like this raise suspicions that circumvention, as defined by IEC / ACEA, was taking place.

Another example has been found in TV testing where, according to the current test standard IEC 62087-2:2015, a TV's power demand is measured at factory setting i.e. out of the box. Yet tests have shown that a minor manual reduction in screen brightness from the box setting can result in an increase in power demand and when the brightness is reset to the box setting the power demand increased even further. Results like this raise suspicions that circumvention, as defined in EU regulations, was taking place.

ECO-CG have developed a number of guiding principles for those tasked with drafting test provisions in standards. However, these principles need to be implemented into measurement standards and verified in practice for reducing the risk of measurement standards being used for circumvention. This will be task of ECO-CG and the relevant technical committees in future. These principles will also increase the awareness of those developing standards on possible misuse or different interpretations of provisions described in those standards. With this, the loss of energy or resource saving potential from Ecodesign or Energy labelling will hopefully be minimised in future.

Annex: Examples of suspect behaviour

The examples in this Annex present a selection of how suspected 'circumvention' is associated with harmonised standard product testing. Some of the examples are already outdated because the relevant standards have been revised in order to avoid these circumventions. Nevertheless, all are listed to illustrate aspects and conditions that might also be encountered by other products' standards, and to raise awareness on specific circumvention and jeopardy effects that can occur.

Electric dishwashers for household use (Dishwasher)

For energy consumption and performance tests, automatic dishwashers for household use have to be loaded with the indicated number of place settings, which are soiled in accordance with standard EN 50242:2016 [11]. With regard to the loading and settings of the machine, the standard requests the tester to follow the manufacturer's instructions.

Dishwasher - Bowl support

According to standard EN 50242:2016, the manufacturer's instructions regarding installation and use of the dishwashing machine shall be followed. In the reported case a separate 'bowl' support, which is marked as 'only for standard tests' or similar on its packaging, is supplied with the machine. This support is attached to the saucer support prongs in the upper rack when loading to the full 15 place settings (standard load as specified by the manufacturer). The support is not mentioned anywhere else than in the standard loading plan, supplied separately by the manufacturer, meaning that it is not intended for use by consumers. [2, p. 12] It might be suspected that the use of the bowl support, solely under test, affects the test results of the dishwasher in terms of (possibly) a lower noise level, a larger number of dishes that can be fitted into the machine or a better drying and cleaning performance.

Dishwasher – Instruction for the removal of accessories

According to standard EN 50242:2016, the manufacturer's instructions regarding installation and use of the dishwashing machine shall be followed. In many manufacturers' dishwashers it is necessary to remove or alter the position of many of the 'accessories' fitted to the appliance when supplied. If the parts are not removed, the declared load will not fit in the appliance. The dishwasher, as supplied, cannot be loaded with the claimed full capacity. Instructions on removal of all the relevant parts are only given in the 'Instructions for Test Laboratories' and are unlikely to be carried out by the consumer in day to day use. [2, p.16] Due to the lower number of dishes that can be fit into the machine without applying the particular instructions requested by manufacturers for testing purposes, much more than 280 cycles (assumption by the regulation for calculation of the annual resource consumption) have to be run, in order to clean the same number of dishes. This type of circumvention does not only affect the energy consumption but also the water consumption of the appliance.

Dishwasher – Specific appliance preparation instructions specifically for testing

A specific instruction on how to adjust the appliance for tests in laboratories is given in the instruction of use ("Information for Test Laboratories only"). One known example says "Three programme runs should be done on the same day and the standard test shall be started the next day. After 12 hours, it is ensured that the appliance has reached ambient temperature." These specific instructions might serve as indication for the appliance to detect being under a test situation. [2, p. 21]

Dishwasher - Water tank

Some dishwashers are fitted with a water storage tank that conserves water (rinsing water or water coming from the mains supply) inside the appliance after the test. The water is used during the pre-wash of the next cleaning cycle in order to save water. The water in the tank being automatically discarded after a certain time if the dishwasher has not been operated. An additional tank cleaning operation may cause an even higher water and energy consumption. Therefore, resource-saving effects can only be realized if the dishwasher is run on a daily basis, which is the case during laboratory performance testing but may not reflect household conditions. [2, p. 28]

Household refrigerating appliances (Refrigerator)

In the harmonised standard EN 62552:2013 [17], the household refrigeration appliance is installed for testing inside a climate controlled room. The refrigerator is tested with closed doors and at a specified temperature.

Refrigerator - Continuously activated display

For certain appliances, the display of a controller is activated each time its door is opened and remains active for a long period unless it is switched-off by pressing a button. The display cannot be deactivated permanently. The user manual states that the energy consumption increases when the display of the controller is lit up. According to the standard, 'the refrigerating appliance shall be set up as in service in accordance with the manufacturer's instructions.' It is most likely that the consumer will not continuously repeat the extra switching-off action required to obtain the declared energy consumption. [8, p. 34]

It has also been observed that the display cannot be switched off manually in some appliances, and it is not possible to change the display time of 24 hours in the settings. The consumer can only set if it will - or will not - turn off after 24 hours. The user manual states not to change the default setting of the screen switch-off function, as the energy consumption of the appliance decreases slightly when the function is activated. According to the current harmonised standard test method (EN 62552-3:2020), no door openings are conducted. Thus, the additional energy consumption caused by the display is not considered in the overall energy consumption of the appliance. [8, p. 35]

Refrigerator – Multiple operation modes

In some frost-free refrigerator-freezers, there are two or more operation modes programmed, namely the 'normal' mode, which is mostly active when door openings are detected, and the 'ECO' or "Holiday" mode, which is activated when the door is kept closed for a longer period. The appliance is automatically switching between the modes according to the managing algorithm of this specific door opening behaviour. The appliances of the reported suspicious case switch to the 'ECO' mode during the energy consumption tests since they reacts to the lack of door openings. Comparing the 'ECO' mode to the 'normal' mode, there are possible differences such as a longer defrost interval, a shorter defrost heater activation time or internal fans that are not running continuously. These specific operation modes lead to a reduction of the energy consumption and differing compartment temperatures at the same controller setting. The 'Eco' mode is active during the conformity testing, while in real life, this very efficient mode is only active for a very limited time, depending on the duration the door actually remains closed at home e.g. when the users are away on holiday. [8, p. 12]

Refrigerator - Alteration of the temperature in the chill compartment

According to COMMISSION REGULATION (EC) No 643/2009 and COMMISSION REGULATION (EC) No 1060/2010 [28], the nominal temperature of chill compartments for calculating the energy efficiency index (EEI) is set at 0 °C, while during the test, the maximum package temperature must be equal or below 3 °C. In practice, during the energy consumption test, the chill temperature is mostly set as high as allowed by the standard (up to 3 °C) to save energy.

Further, measuring the storage volume of the chill compartment in accordance to EN 62552:2013 may result in a total storage volume greater than the real volume. This implies a better EEI. The new standards EN 62552-1,2,3:2020 already address this issue. [4, p. 36]

Refrigerator - Cool down function in frost-free refrigerator-freezers

Some frost-free refrigerator-freezers are programmed with a cool-down function which purpose is to minimize the temperature increase on the frozen food when the defrost function is activated. In some cases, the cool-down starts just after the maximum testing time specified by EN 62552:2013 and therefore, the extra energy consumption of this function is not incorporated into the test result. The new standards EN 62552-1,2,3:2020 already address this issue. [4, p. 37]

Refrigerator - Interpolation of temperatures

The interpolation procedure stated in EN 62552:2013 makes it possible to choose more favourable thermostat settings for calculating the energy consumption. The interpolated temperatures could be higher than the target temperature. Therefore, the manufacturer can test the appliance and use the most favourable results for the declaration of conformity. The new standards EN 62552-1,2,3:2020 already address this issue. [4, p. 37]

Household electric ovens (Oven)

According to EN 60350-1:2016 [13], the standard test is conducted in two consecutive steps. The first step of the test cycle is the measurement of the energy consumption. This is done with the oven loaded with a brick. The second step is the temperature measurement of the empty oven. Thus, after the energy consumption is measured, the door is opened, the brick is removed, the oven is continuously operated and the temperature measurement starts.

Oven – Removable items

The harmonized standard EN 60350-1:2016 states that removable items specified in the user instructions, and not essential for the operation of the appliance, shall be removed before the volume measurement is carried out if this is described in the user instructions. According to some user manuals, for some recipes the oven cavity must be empty, i.e. the removal of the side racks and removable side walls (e.g. optional catalytic walls) is required. In the tested case, the measurement of the oven volume is done after removal of shelf guides, which leads to a better energy efficiency index being calculated as it is the ratio between energy consumption and volume. [5, p. 28]

Oven – detection of door opening

The test cycle according to EN 60350-1:2016 consists of a subsequent temperature measurement of the empty oven in conjunction with the previously performed energy consumption measurement. The first step of the cycle (measurement of the energy consumption) is done with the oven loaded with a brick and necessarily after this step, the door has to be opened to remove the brick for the next step (temperature measurement of the empty oven). In the reported case, it has been observed that the opening (and re-closing) of the oven door caused a significant increase of the temperature in the interior of the oven. Thus, the energy consumption measurement was performed at a lower temperature as the temperature indication is set. [5, p. 27ff]

Household washing machines (Washing machine)

The energy consumption of a household washing machine is predominantly influenced by the washing temperature. The higher the temperature, the higher the energy consumption is. In order to save energy without compromising the washing performance, the washing temperature may be lowered in favour of the amount of detergent, agitation of the load, or cycle times. Energy labelling and ecodesign requirements for washing machines under Commission Regulation (EC) No 1015/2010 [27] and Commission Regulation (EC) No 1061/2010 [29], are based on 60 °C and 40 °C cotton standard programmes, which have to be indicated on the front-display of the device. [4, p.48] The appliances are tested according to the applicable standard EN 60456:2016 [14]. While these documents do not specify an upper load capacity, the actual temperature in the washing process or limit the programme duration, it can already be stated that the revised Ecodesign regulation (Commission Regulation (EU) No 2019/2023) and EN 60456:2016/A11:2020 [15] address the issue of programme times and temperature [5, p. 48].

Washing machine – compensation of lower temperature

In the reported case, the actual temperature of the water during the washing process in the ECO-programme is lower than declared in the programme name. To fulfil the requirements concerning the washing index (performance of a washing machine measured under predefined conditions in relation to the performance of a reference machine) the potential losses in washing performance are compensated by higher agitation of the load and cycle times of more than six hours. In real life, such programmes are seldom selected due to long cycle times. [5, p. 48]

Washing machine – influence of high load capacities

Some washing machines have rated load capacities of 10 kg or higher. The load capacity is part of the calculation of the energy efficiency index (EEI) of the appliance, whereby a high load capacity results in a more advantageous EEI. In real life, however, consumers seldom load such a machine to its full extent. [5, p. 49]

The advantageous effect of a high load capacity on the calculation of the energy efficiency index is also exploited in the case of a washing machine with two drums. In the reported case, the upper drum has a capacity of 4 kg and the lower drum 8 kg. Even though the smaller drum is able to perform the washing cotton standard programmes 60 °C and 40 °C, it is declared as not being able to perform those. Therefore, the energy and water consumption as well as the functional performance of the upper drum is not measured and shown to consumers via the energy label. In this case, the consumer is misguided by the information on the energy label, which refers only to the lower drum with the higher load capacity and thus, only to a part of the appliance. [5, p. 49]

Household tumble dryers (Tumble dryer)

According to the standard EN 61121:2013 [16], wet laundry of a defined initial humidity is dried down to a defined final humidity. The energy and time needed is measured, as well as the efficiency to condensate the extracted water (for condensing dryers).

Tumble dryer – specific preparation instructions

According to the standard EN 61121:2013, the dry cotton programme shall be selected to measure the condensation efficiency of condensation tumble dryers in the drying test, and the manufacturer instructions shall be followed for appliance set up. Both the mass of the test load before and after drying and the mass of condensed water inside the container shall be determined. If the appliance has not been operated for more than 36 hours, the first cycle shall not be evaluated.

Certain household tumble dryers have a statement in the instructions regarding specific preparation before commencing tests according to standard EN 61121:2013. In the specific case, it is required that a 3 kg load is prepared to 70 % residual moisture content, and the tumble dryer is loaded. Subsequently, the tumble dryer shall be operated in the normal cotton programme before commencing EN 61121:2013 tests. It is possible that this specific set of requirements of pre-acclimatization could trigger a different performance profile in order to reach more advantageous results in terms of the energy consumption of the appliance.

Televisions (TV)

According to the standard IEC 62087-2:2015 (specified signals, screen resolution and media) [21], a TV's power demand is measured at factory setting. i.e. out of the box. A standardised test movie, consisting of fast moving images only, is broadcasted for measuring the energy demand. Prior to the start of the standardised test movie, a countdown clip is shown. This countdown lasts for 10 seconds and does not contain any fast-moving images. After the 10 seconds, the movie content is played.

TV – manual adjustment of the factory setting

In the reported case, it was observed that the power demand increased if the factory setting of the TV was adjusted manually for the first time. In concrete terms, the brightness value was 45 in factory settings, corresponding to 71 W. However, if the brightness decreased by one point to a value of 44, TV's power demand increased to 90 W. Even if the brightness was set back to the factory settings (45), the power demand remained high. [3, p. 12] The impact of the manual alteration of the brightness is not covered by the standard test, as the test is conducted at factory settings.

TV – automatic brightness adjustment function

Some TVs have an automatic brightness adjustment function that is activated by default. This function analyses the broadcast program and when fast moving images are detected, the brightness of the television is reduced automatically and the power demand of the television decreases. As a result, the measured energy consumption of the television is significantly lower compared to a broadcast video without fast moving images. [3, p. 17] In real life usage, images moving as fast as in the test video occur only seldomly, if ever. If no fast-moving pictures are detected, the brightness adjustment function is not triggered. Thus, the power demand of the television is not reduced, and the energy consumption in real life usage is higher than under test.

The issue of the detection of fast-moving images is already well known. Recently, a new test video has been developed by CLASP's Europe program: A new ten-minute test video sequence that can serve as an alternative to the existing IEC 62087:2015 test video to measure the energy consumption of HDR (high dynamic range) televisions. The alternative test video takes into account and better reflects normal program content compared to the IEC 62087:2015 standard test video sequence. It offers the same average brightness level (34 %) as IEC but, has fewer cuts in the video content, which makes it more representative in terms of normal program content. [3, p. 24]

Air-to-air heat pumps (Heat Pump)

The test methods for determining the capacity and efficiency for air-to-air heat pumps are described in EN 14511:2018 [9]. In addition, EN 14825:2018 describes calculation methods to determine the average performance during the heating season, the Seasonal Coefficient of Performance (SCOP) factor. In case frosting takes place on the outdoor unit during the test, both the heating and defrosting period are included in the evaluation of the test. However, the evaluation period is limited to a maximum of three hours to limit the cost of the tests. The rated heat output (with corresponding efficiencies) that are used in the calculations can be defined freely (with some limitations) by the manufacturer.

Heat pump – declaration of low capacity

In the reported case, it is suspected that the declared energy efficiency of the product on the energy label and supporting data sheets is considerably higher compared to what has been measured in real installations in the field, especially in cold and humid climates. As a consequence of the energy efficiency calculation method, the efficiency of a heat pump normally increases with lower capacity, down to a certain limit. Declaring a lower that actual capacity of the heat pump beneficially gains a high energy efficiency declaration of the appliance. [4, p. 14]

Room Air Conditioners (Air conditioner)

The EER (energy efficiency ratio) is a measure of energy efficiency (cooling capacity divided by power input). The higher the value, the more efficient is the appliance. The cooling capacity is not listed in the verification Annex of the ecodesign / energy labelling regulations, nor in the currently harmonised standard EN 14511:2018, therefore Market Surveillance Authorities (MSA) may ignore this parameter (not to be verified for the ecodesign / labelling regulations), also due to the lack of verification tolerance. However, the latest interpretation is that when no tolerance is defined in a regulation, the tolerance is zero, and the declared value has to comply with the measured value [1, p. 21].

Air conditioner – Misuse of verification tolerance

In the reported case, the EER measured by the manufacturer, which is given in the test report of the technical documentation, is 2,5 and thus below the declared value of 2,6. The measured value in the MSA laboratory (EER=2,72) fully confirms the declared value. However, the manufacturer has achieved a better product positioning by misusing the verification tolerance.

The cooling power measured by the manufacturer in the test report of the technical documentation is 2.8 kW. This value is 5 % lower than the declared value of 3.0 kW. The measured value in the MSA laboratory is 2,83 kW, confirming the result of the manufacturer test report, but not the declared value of the cooling capacity. This means that the consumer purchases a model with a cooling capacity lower than the declared value. [1, p. 21]

For this model, the mere verification through laboratory testing (with no documental inspection) would result in a compliant product for both Ecodesign and Energy labelling, because the result of the MSA laboratory testing, and the EER declared values are within the permitted tolerance. Because of the reduced cooling power in comparison to the declared value, it is easier to achieve compliance with Ecodesign requirements and labelling. [1, p. 21]

Electric motors – hypothetical assumption

The harmonised standard EN 60034-2-1:2014 [12] specifies: 'Tests shall be conducted on an assembled machine with the essential components in place, in order to obtain test conditions equal or very similar to normal operating conditions. Externally accessible sealing elements may be removed for the tests, if an additional test on machines of similar design has shown that friction is insignificant after adequately long operation.' The removal of externally accessible sealing elements may change the energy consumption of the motor. Although the difference may be small, it can be enough to claim compliance or not.

Hidden software – hypothetical assumptions

Energy using products, e.g. white goods, televisions, room air conditioners, or heaters may theoretically comprise hidden software/sensors that detect the specific ambient testing conditions of the standard procedure and run specific algorithms that result in lower resource consumption of the tested device. The very narrow range of the electrical voltage 230 V +/- 1 % under test might easily be detected by the appliance. As in real life, the electrical voltage fluctuates in a bigger range, the stable voltage might be used by the appliance to alter the operation to a specific test conform mode, which leads to advantageous results in the resource consumption. [4]

Another purely hypothetical assumption is that white goods may theoretically comprise hidden software that runs a certain algorithm for a pre-set number of cycles that consume significantly less resources. Since, products tested by MSAs are 'new' products, this algorithm may cover all test runs performed within market surveillance testing. However, in real life conditions, although consumers will experience this reduced consumption, it will be for a limited time and the device will revert to a different algorithm and run it for the rest of its use life. [4]

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4 FOCUS ON DEVELOPING COUNTRIES

How Can Residential Demand in Low Electricity Access Countries Be 100% Met by 2030? A Case Study of Burkina Faso

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Abstract

As the last decade countdown to 2030 starts, the challenge for participating countries to the global sustainable development goals agenda remains vivid, particularly amid the multifaceted effects of the Covid-19 pandemic. The latter has revealed unforeseen opportunities for accelerating the energy transition in countries with low access to electricity services, particularly in sub-Saharan Africa where electrification efforts have been mostly driven by the implementation of faster and cheaper solutions for residential electrification without any country-wide least-cost electrification analysis. Additionally, emergency electrification decisions can lead to overlooking long-term planning. In West Africa, Burkina Faso stands among the region's leaders in solar energy development, yet it is faced with around 80% of its households lacking (reliable) access to basic electricity services.

This paper highlights the need for medium/long-term planning in residential electrification, leveraging on a previous study featuring the spatial electrification modelling tool OnSSET[199], by: (1) determining the optimal combination of grid and off-grid systems to fully electrify Burkina Faso, in view of substantiating the progress and gap between a 15-year and a 10-year timeframe to 2030; (2) questioning the effectiveness of Covid-led emergency deployment of solar home systems solutions. The results highlight the fundamental role of off-grid solar PV, hydro, and wind technologies in bridging the electricity access gap in both cases. Nine years from now, the urgency of holistically rethinking the provision of electricity services to the residential sector appears crystal clear, through science-for-policy approaches and increased local content across the renewable energy supply chain.

Introduction

Less than nine years to the 2030 milestone of universal access to electricity catalysed by the United Nations' Sustainable Energy for All initiative, concerns are being raised over recent efforts to advance the Sustainable Development Goals (SDGs) being countered in the face of the pandemic [1]. Building forward better, stronger and greener has been the driver for global and regional development institutions at the forefront of sub-Saharan Africa (SSA)'s transformation. With energy recognized as a multiplier of development, a post-COVID-19 SSA cannot be contemplated without rethinking the long-standing issue of energy access.

Burkina Faso, a high electricity access deficit country (20% as of 2018 [2]) has an electricity mix dominated by fossil-fuelled thermal power plants, running on imported fuels. In a world affected by a pandemic crisis, Burkina Faso has been one of the least Covid-affected countries in West Africa, with a relatively low mortality rate [3] (at the time of carrying out this study). Yet, even with low Covid-19 cases, unforeseen events such as the Covid-19 pandemic unearth and amplify existing and underlying dysfunctions and crises including those related to health, energy, education, and the wider economy. Indeed, some mitigation measures included the

[199] It has been widely recognized that the geographies of electricity demand, supply and consumption are key to addressing the question of expanding power generation capacity. This implies geo-referenced information to build upon using tools such as OnSSET, which is fully describes in another paper by the same authors (https://doi.org/10.1016/j.energy.2020.117471).

close down of local goods and food markets, in a context where such markets are critical to the livelihoods of its players, mainly originating from rural/peri-urban areas. This pandemic brought about unprecedented and multifaceted challenges, to which various ministerial departments of Burkina Faso, beyond the health sector, provided quick responses. Energy-related social measures were announced during a press conference on April 4th, 2020 by the then Minister of Energy. Those measures targeting 675,000 households in both urban and rural settings, were due to take various forms, from electricity tariff exemptions and tariff reduction to Solar Home Systems (SHSs) subsidies. The latter were implemented within the framework of an existing project named "solar backup", run by the National Agency for Renewable Energy and Energy Efficiency [4]. Some of these social measures, particularly those related to SHS subsidies, met with lots of speculation amid an equally large number of appreciative online posts on the virtual platforms of both the Ministry of Energy and the National Renewable Energy Agency. A few instances could read:

"- It is said that all these social measures seem to be restricted to the capital city. What about the rest of us, living in smaller cities/rural areas?"

"- The widespread keen interest sparked by these subsidies on solar home systems (SHSs) shows that these technologies were not affordable to most households in the first place".

Quantitative data obtained from the National Renewable Energy Agency indeed highlight that in practice, the two largest cities – Ouagadougou and Bobo-Dioulasso – altogether represented over 50% of the beneficiary areas, with the former (also the capital city) holding the lion's share with 48% [5]. Furthermore, among beneficiaries around Ouagadougou, at least 64% are located in already electrified urban/peri-urban areas, and around Bobo-Dioulasso, at least 60% of them already live in electrified urban/peri-urban settings [5], [6]. This means that less than 40% of the beneficiary households of the SHS emergency plan were in non-electrified peri-urban/rural areas of the two largest cities.

A recent study aimed at determining the optimal combination of grid and off-grid systems using geospatial data to fully electrify Burkina Faso (alongside another West African country, Côte d'Ivoire) [7] corroborates the scholarly and regional argument for complementary inputs of the grid and off-grid solutions in such countries experiencing rapid population and economic growth [8]–[10]. However, experiences of electrification efforts across SSA show that electricity access has mostly been driven by short-sighted approaches instead of long-term planning with coherent grid/off-grid mapping [11]. The rationale behind "leaving no one behind" combined with political will culminates in the implementation of faster and cheaper solutions for last-mile electrification. Notwithstanding, the choice of providing electricity through off-grid technologies is most often not based on holistic, country-wide least-cost electrification analysis [12]–[14]. Emergency electrification decisions in SSA have been shown to incur unsound investment in generation infrastructure [15], all of which can result in areas served by short-term off-grid solutions being, in fact, viable for grid extension from a techno-economic perspective accounting for electricity demand projections and population growth. SSA countries thus appear to operate in a lock-in situation of emergency reactivity overlooking a sound and informed long-term planning able to capture short-term externalities such as pandemic-led crises.

This study seeks to provide a geospatial modelling-based analysis of the quantitative coverage and financial gap to the 2030 milestone for universal access to electricity in Burkina Faso. It leverages the results of a previous study by the same authors [16] with the OpeN Source Spatial Electrification Toolkit (OnSSET) and includes an analysis of the implications of the emergency SHS subsidies.

The remainder of this paper is organised as follows. Section 2 covers the methods and data, and Section 3 presents the modelling results. Section 4 concludes and suggests avenues for further research.

Methods and Data

The methods and most of the data employed in this study are similar to [7], which can be consulted for further description.

Methods

In OnSSET, energy resource availability is combined with geographical and demographic conditions to model the cost-optimal technology for fully electrifying the residential sector within a user-defined timeframe. In [7], the cost-optimal electrification pathway by the year 2030 was modelled, in line with SE4All's (Sustainable Energy for All) goal of universal access to electricity by 2030. OnSSET integrates a costing algorithm based on the Levelized Cost of Electricity (LCOE) of grid extension, stand-alone diesel genset, diesel mini-grid, stand-alone and mini-grid solar PV, mini and small hydro, and mini-grid wind turbines. The electricity access tiers of SE4All's Global Tracking Framework [6] were used. Electricity access was modelled at 1 km x 1 km resolution for low diesel prices according to two electricity demand scenarios. A country-wide low demand scenario, corresponding to Tier 2 access in rural areas and Tier 4 in urban areas, and a high demand scenario, corresponding to Tier 3 access in rural areas and Tier 5 in urban settings.

In this paper, the base year considered is 2020, instead of 2015 as in [7]. The final year remains 2030 with the assumption that efforts are accelerated to meet the 2030 Agenda. A comparison of the technology options and investment requirements for the modelling timeframes 2015-2030 (in [7]) and 2020-2030 (the present study) will be performed, leveraging on delivery progress over the past five years. The low diesel price scenario is chosen alongside low electricity demand, the reason being that the modelling results in [7] highlight no tangible difference in least-cost technology split between low and high diesel prices scenarios for any demand level. Furthermore, and specifically due to the Covid-19-related socio-economic setbacks, a high electricity demand scenario (Tier 3 rural access and Tier 5 urban access) has become less probable within a 9-year timeframe, although not impossible.

Data

Three types of data were used, with the same assumptions as in [7]: GIS layers, techno-economic, and household data. Data about the total installed costs of each off-grid technology, the typical costs of transmission lines, capacity factors, discount rates, electrification rates and households specifications (existing and forecast sizes and electricity demands in rural and urban areas) were collected from the International Renewable Energy Agency and the World Bank databases, as well as from various sources such as [17]–[23]. GIS layers for population densities, administrative boundaries, existing and planned electrical grid, substations, roads, land cover, elevation maps, night-time lights, global horizontal irradiation, wind speeds and travel time were acquired and when necessary, further processed into ArcGIS to suit the needs of the analysis. Solar PV restrictions and small and mini hydropower potentials maps were also developed.

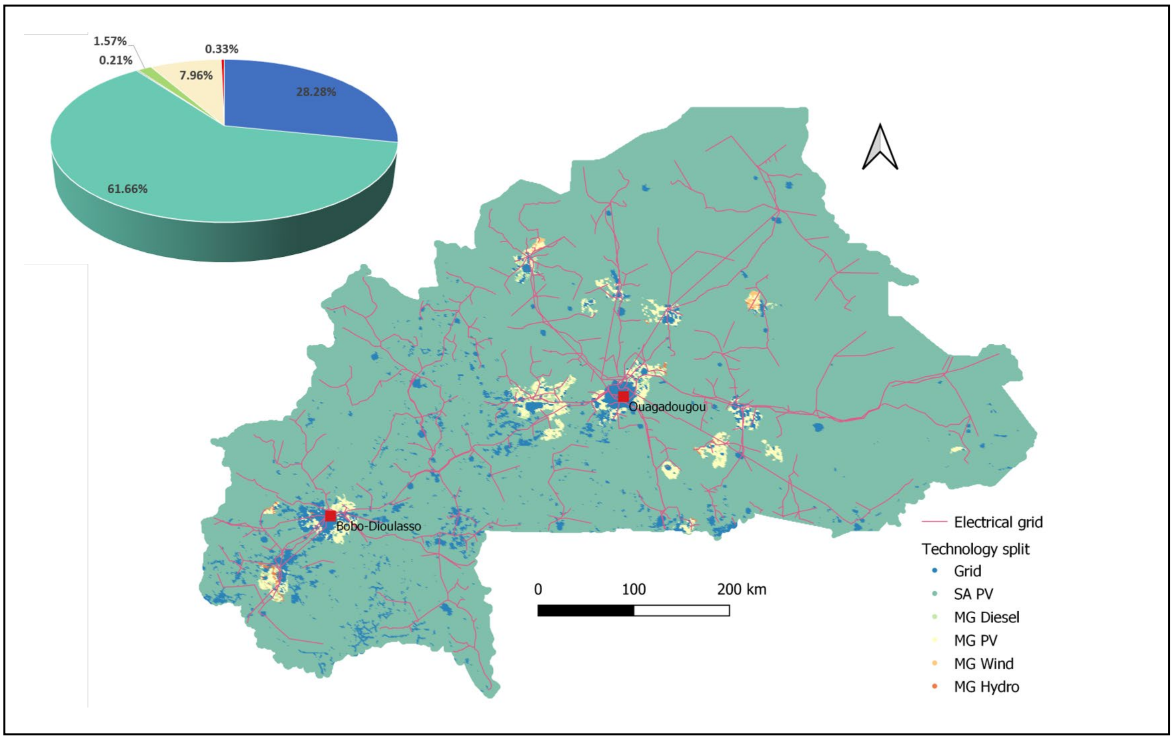
Time-sensitive information presenting substantial changes since the publication of the study in [7] has been updated, namely population densities and distribution, existing and planned electrical grid and substations, and electrification rate in the base year. Although national grid price has only sensibly decreased between 2015 and 2020 accounting for the coming online of large-scale solar PV plants, this change was included in OnSSET input techno-economic data. Although no actual number of beneficiary households was officially provided – the Ministry of energy envisioned to reach at least 25,000 people, i.e. around 5 000 households –, it appears from bilateral discussions with relevant entities that SHS roll-out has not yet been effective in certain locations due to the high demand levels and low supply options. Hence, it may be reasonably assumed that the ratio of the number of beneficiaries over the total number of households for any given location is sufficiently low to justify not considering such location as "newly electrified". From the initial OnSSET analysis to 2030 in [16], the locations covered by the SHS emergency plan are mostly "grid areas". It could however be argued that probably some parts/full parts of some locations belong to mini-grid photovoltaics (PV)/SHS areas (but mostly mini-grids). This uncertainty comes from the spatial resolution of 1 km x 1 km which provides good granularity, yet it is difficult to accurately set the boundaries of each location (especially neighbourhoods in peri-urban areas). It is, thus, reasonably assumed that even though these are not reflected in the model as newly electrified zones, the corresponding locations would, at best, grow as mini-grid areas within a 10-year timeframe.

Results

Building forward from 2020 to 2030

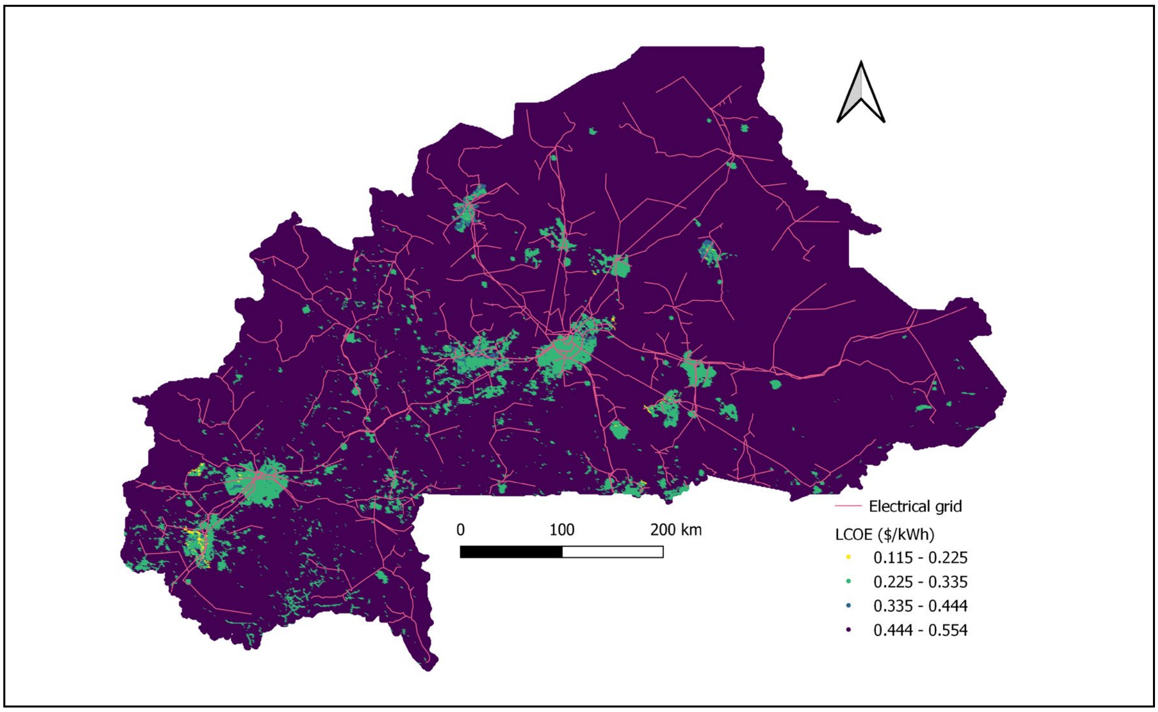
The modelling results show that off-grid PV systems, particularly solar PV standalone systems or SHSs, remain the main electrification means for Burkina Faso by 2030 (Figure 1). As demand rises, the number of people served by the grid slightly increases and mini-grids become cost-competitive compared to standalone, covering almost 40% of the population. Off-grid diesel systems play no role in the technology mix, even with the assumption of low diesel prices assumption, and neither do small and mini-hydro.

Figure 20. Optimal technology split for low electricity demand with low diesel prices in Burkina Faso



The mapping of LCOEs (Figure 2) shows that grid and mini-grid areas enjoy the lowest values whereas stand-alone PV areas have relatively high LCOE. Such values are below the average ability to pay of $0.372/kWh [24], [25] for only 6.3% of settlements. This means that overall, LCOEs are higher than the ability to pay.

Figure 21. LCOE values for low electricity demand with low diesel prices in Burkina Faso



2030 from 2015 vs. from 2020: Progress and gap

Table 3 summarises the key highlights in terms of optimal technology split, LCOEs and investment requirements by 2030 depending on the base year considered, 2015 and 2020. The 2020-2030 modelling period yields slightly higher total investment costs with an increased deployment of distributed generation. Mini-grids gain more prominence in the optimal technology split of 2020-2030 as population distribution and density evolves, and technology costs decrease. The LCOE for the grid is slightly lower for the later period due to the minor reduction in the overall cost of the national grid owing to the growing penetration of utility-scale solar power since 2016. Such a reduction, however, remains too low to drastically bring down the cost of the national grid given that the share of large-scale PV (with lower operating costs) is still insignificant in the overall national mix.

Table 11. Technology split and LCOEs for 2015-2030 and 2020-2030

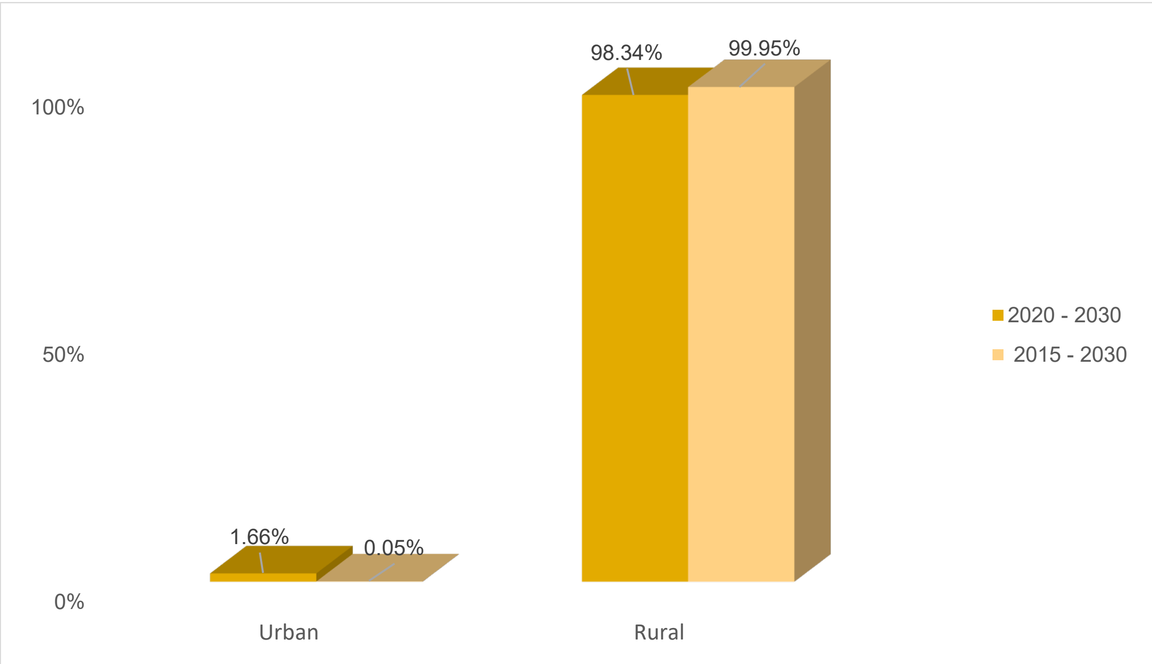
<table>
<tr><th colspan="2" rowspan="3">Technology</th><th colspan="6">Low electricity demand and low diesel price scenario</th></tr>
<tr><th colspan="2">Technology split</th><th colspan="2">LCOE ($/kWh)</th><th colspan="2">Investment (billion $)</th></tr>
<tr><th>2015-2030</th><th>2020-2030</th><th>2015-2030</th><th>2020-2030</th><th>2015-2030</th><th>2020-2030</th></tr>
<tr><td colspan="2">Grid</td><td>30.52%</td><td>28.28%</td><td>0.26 - 0.34</td><td>0.25</td><td>8.21</td><td>7.67</td></tr>
<tr><td rowspan="2">Off-grid</td><td>Stand-alone diesel</td><td>0.00014%</td><td>0%</td><td rowspan="2">0.43 – 0.51</td><td rowspan="2">0.12 – 0.56</td><td rowspan="2">1.55</td><td rowspan="2">2.12</td></tr>
<tr><td>Stand-alone PV</td><td>62.41%</td><td>61.66%</td></tr>
</table>

	Mini-grid wind	0%	0.21%			1.62	2.23
	Mini-grid diesel	0.11%	1.57%				
	Mini-grid PV	6.91%	7.96%				
	Mini-grid hydro	0.05%	0.33%				

Moreover, considering the 50% SHS subsidy and assuming a 20% - 90% actual roll-out (of the initial target of 5 000 beneficiary households), the total costs of the emergency plan could be estimated at between $280 000 and $1.26 million. This represents, at best, 0.06% of the required investment for stand-alone PV by 2030. However, it is to be recalled that in practice, the rollout largely occurred in already electrified settings of the two largest cities. From both the 2015 and 2020 levels, most of these peri-urban/rural areas would be mostly cost-effectively served by the grid by 2030. Therefore, this emergency plan would lead to redundant/unsustainable efforts, should additional generation and transmission infrastructure come online as expected before the Covid-19 pandemic. Overall, the actual coverage zone of the emergency plan does not appear cost-effective with regard to the goal of universal electricity access by 2030.

In addition, the results reveal comparable patterns regarding the proportions of distributed generation (stand-alone and mini-grid systems) in urban and rural areas by 2030 (Figure 3). The values are slightly higher than in [26] whereby the authors considered three demand categories: heavy industry, urban residential/commercial/small industries, and rural residential/commercial. Therefore, it could be reasonably argued that combining the results of the present study with industrialisation and commercial mapping could enhance these values closer to a realistic scenario. However, given that Burkina Faso is – and expected to remain so in the coming years – at a low level of industrial development besides gold mining activities, the modelled values would only be slightly changed and be comparable to the 90% share of distributed generation in rural areas found in [26].

Figure 22. Shares of distributed generation by 2030 in Burkina Faso in the low demand-low diesel price scenario



Conclusions and future research

The results demonstrate that most of the population will be cost-effectively served with distributed PV generation, yet with LCOE values mostly higher than the average ability to pay. Though Burkina Faso's SHS emergency plan may have contributed to increasing electricity access for a few households, it remains a drop in the ocean, as well as being of short-term impact on this nation-wide long-standing issue. Virtually all areas covered by the emergency plan have been shown to be cost-effectively served by either renewable-based mini-grids or the grid by 2030, following a country-wide spatial electrification analysis. Moreover, non-hydro renewable energy such as solar PV and wind can play crucial roles in meeting the 2030 target of universal access to electricity even in a scenario with low electricity demand and low diesel prices. On the whole, the short-sightedness of this Covid-led electrification decision unearths the urgency to rethink the provision of electricity services to serve current and future needs for long-term, sustainable impact and development. This necessitates a holistic, science-for-policy approach informed by solid data and rigorous scientific methods and supported by "prosumerism" behaviour. Indeed, medium- and large-scale deployment of solar PV systems requires duly considering the entire supply chain to avoid unsustainable installations in locations lacking the human and technical capacity for adequate operation and maintenance. FasoEnergy, the first solar panel manufacturing factory in West Africa, inaugurated in September 2020, is a crucial step towards increasing the local content of energy projects and achieving such a long-term vision.

This study provides a stepping-stone for building a sound scientific knowledge base for medium- to long-term electricity planning in Burkina Faso with potential replication to other SSA countries, particularly for more Covid-19-hit (by mortality rate) and high energy deficit countries in West Africa such as Mali, Niger and Liberia. Indeed, it appears even more relevant for countries with higher incidence rates and impact of Covid-19 to develop sound planning of electricity access for their most vulnerable segments of the population. It also appears relevant to further contemplate the interlinkages between SDG 3 "Good health and well-being" and SDG 7 "Clean and affordable energy", as part of a holistic approach towards achieving them in a proactive fashion. Further research should include residential and commercial electricity demand and model the long-term cost-optimal generation mix for grid extension with a specific emphasis on green energy. Other research avenues could focus on the socio-technical dimensions of access to electricity/energy services exploring the energy/gender/inequalities nexus in medium and long-term planning, in order to support a more inclusive and just energy transition in a region where women stand at the heart of household energy management and are the most vulnerable to the effects of energy poverty, particularly in rural areas.

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Energy efficient and climate friendly cooling in Southern and Eastern Africa

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Abstract

Growing populations, urbanization and rising living standards in the regions of the East African Community (EAC) and Southern African Development Community (SADC) are driving an increased demand for cooling services. If policies are not implemented in response to this demand, the electricity consumption for room air conditioners and residential refrigerators is expected to increase by 2.5 times by 2040 compared to the current consumption.

The United Nations Environment Programme's (UNEP) United for Efficiency (U4E) initiative, East African Centre of Excellence for Renewable Energy and Efficiency (EACREEE) and SADC Centre for Renewable Energy and Energy Efficiency (SACREEE) are working together to adopt sustainable cooling solutions without causing undue harm to the environment. The aim of the project is to collaborate in order to multiply the effect on the ground through a broader regional collaboration.

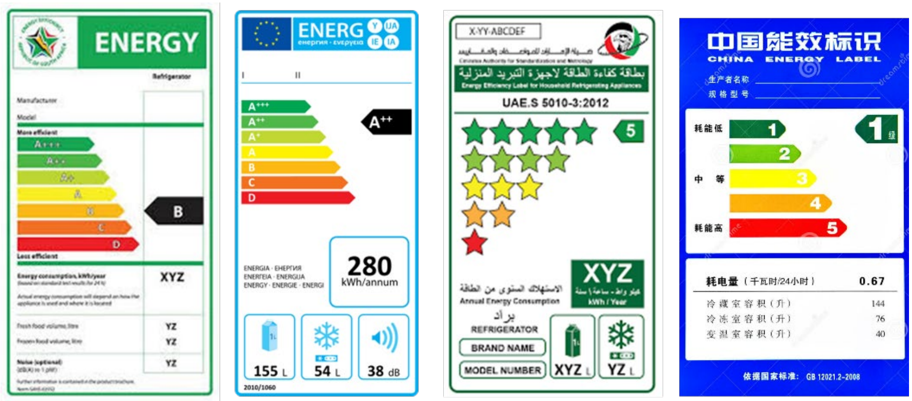
The project is developing a policy framework for energy efficient and climate friendly refrigerators and air conditioners with the ultimate goal to implement Minimum Energy Performance Standards (MEPS) and labelling for both products. The MEPS are being developed in consultation with the countries and regional bodies to leverage the policy effects. Up to date, a regional market assessment was conducted, technical notes and the MEPS and labels itself were developed. Currently, the policies are being discussed with the countries to tailor them for adoption.

1. Introduction and importance of energy efficient cooling in the regions

Growing populations, urbanization and rising living standards in the East African Community (EAC) and Southern African Development Community (SADC) regions will drive increased demand for cooling services, such as air conditioning and refrigeration. In addition, the warming climate in the EAC and SADC regions continues to enlarge the stock of air conditioners and refrigerating appliances. EAC and SADC countries have put in place robust electrification policies and targets with the aim to increase access to electricity and thus to achieve universal access to energy services. If energy efficiency policies are not implemented in response to the energy demand, it is expected that the electricity consumption used for room air conditioners and residential refrigerators by 2040 will increase by 2.5 times compared to the current consumption [1].

In addition, the Montreal Protocol has evolved from focusing on ozone layer protection to also addressing climate change mitigation with the 2016 Kigali Amendment establishing a framework for reducing global hydrofluorocarbon (HFC) use. This shift presents an opportunity to link the HFC phasedown with the deployment of energy efficient cooling equipment and thus provide benefits in terms of greenhouse gas reductions, technical and economic synergies, and reduced dumping of environmentally harmful products in developing countries. HFC based refrigerants with high Global Warming Potential (GWP) are still in use in refrigerating appliances and air conditioners in both regions [2]. The absence of policies and regulations to enforce minimum energy performance standards (MEPS) and labeling in several countries in the two regions opens doors to dumping of inefficient and environmentally harmful cooling products. MEPS are one of the key policy options to accelerate the market transformation to energy efficient and climate friendly appliances. In parallel to MEPS, product labeling facilitates the delivery of key purchase information directly to consumers. This helps customers to inform the purchasing decision such as using a star or tier system to allow comparison of each appliance's electricity consumption. Currently, consumers are not provided with clear and consistent information on labels when purchasing a refrigerator or air conditioner. Many of the appliances that are offered in the market already have a label as they are primarily imported from countries (outside EAC and SADC) or a nearby market with labeling requirements. This situation is confusing for consumers as they find themselves among a large range of different labels that are not comparable or that are even in foreign languages, examples of labels are presented in figure 1. The problem mostly applies to room air conditioners, as there are no air conditioning manufacturers in both regions. In most countries in the EAC and SADC, inefficient room air conditioners and residential refrigerating appliances are common [2]. Cooling appliances have a large saving potential and energy efficient products can play an important role in decreasing the load on the electricity grid.

Figure 1. Examples of labels circulating in EAC and SADC



Labels from (left to right): South Africa [3], European Union [4], United Arab Emirates [5], China [6]

2. Description of the project

The SADC Centre for Renewable Energy and Energy Efficiency (SACREEE), East African Centre of Excellence for Renewable Energy and Efficiency (ECREEE) and the United Nations Environment Programme's (UNEP) United for Efficiency Initiative (U4E) are working together to implement a regional harmonization project on energy efficient and climate friendly cooling, with key focus on residential refrigerating appliances and room air conditioners. The project includes 21 countries, which six EAC countries (Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda) as well as 16 SADC countries (Angola, Botswana, Comoros, Democratic Republic of Congo, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe. The United Republic of Tanzania is member of both EAC and SADC and appears therefore in both regional lists.

The aim of the project is to develop harmonized MEPS and labels, which is to be reached along four key components, namely:

- A market assessment to analyze the markets on room air conditioners and residential refrigerating appliances in both regions.
- Technical notes that provide an overview of the global market, policy trends and technical recommendations based on the findings of the market assessment.
- Engagement with Technical Committees to develop the regulatory framework including the development of procedures for the implementation at the national level. In addition, the Technical Committees ensure the collaboration with key actors in the regions active in Standards and Labelling on both cooling products.
- And lastly, the final objective, the development of MEPS and labels in a harmonized manner. This component also includes support for implementation of the MEPS and labels adoption process at the national level.

The project was kicked-off in June 2020 with a high-level inception meeting with the aim to inform on the needs of energy efficient and climate friendly cooling and to present the project to the participants, which were representatives of energy ministries and standards bodies. As a next step, the regional standards bodies were requested to officially adopt the project by a voting of the member countries on the implementation of the project, which was successfully completed. Thereafter, the project was enabled to start and the first component, which is the market assessment, was commenced.

In a next step, the technical notes were developed which picked up the results of the market assessment findings to deliver some first technical recommendations on where to set the MEPS. Both of these key reports were presented and discussed during a subsequent regional workshop with all of the 21 countries in December 2020. In addition, the workshop aimed to solicit comments from EAC and SADC countries and key stakeholders on both documents. With the background of the market assessment report and the technical notes the involvement of the Technical Committees was established in order to develop the regionally harmonized MEPS together with the input of the countries and to tailor the policies to the regions. The Technical Committees are key as their role is amongst others to review the MEPS and labels for adoption in the countries. In that context, Terms of Reference have been developed for the regional and national Committees and several meetings were held to commence the collaboration. This enabled a holistic consultation process on the draft MEPS and labels that were developed along the U4E model regulation guidelines, which are a best practice template that were developed with key stakeholders from the public and private sector [7]. After presenting the proposed MEPS at a regional meeting in September and October 2021 the project is currently undergoing national consultation meetings with each of the 21 countries. Once the national consultations are concluded the MEPS will be finalized in a regional coordination meeting and then taken forward by the countries for implementation. All of the above-described components are presented in more detail below to give more insights into the key parts of the project.

3. Insights into market assessment and technical notes

As mentioned, the project was kicked-off with a market assessment on cooling products for both regions which provided detailed information about the different market dynamics and trends. The market assessment covered the 21 countries of the EAC and SADC regions and was conducted in order to provide the basis for the policy development. As a methodology for the data collection, questionnaires were sent out to focal points as well as the private refrigeration and air conditioning sector, data from ministries and authorities was obtained and an internet research was conducted. This data was complemented by project partner data, such as from a regional lighting market assessment, and existing high-level data from U4E to support data validation. In the following key conclusions of the market assessment are presented.

Findings of the market assessment

Energy Policies: Energy policies, including energy efficiency policies, play a pivotal role in transitioning markets to energy efficient cooling. The market assessment revealed that in the EAC, 60% of the countries have put in place energy policies covering the energy sector. Energy efficiency strategies are available in Kenya and Uganda, which provide the roadmap of the measures the countries plan to undertake to ensure that different sectors are energy efficient, including the cooling sector. In the SADC region, the market assessment revealed that almost 90% of SADC countries have put in place energy policies covering the entire energy sector. In terms of energy efficiency strategies, half of the SADC countries have put in place strategies and action plans with the aim to establish standards and labeling programs for household appliances. The energy efficiency policies help the member countries to mitigate significant carbon emissions and achieving their National Determined Contributions (NDCs).

Environmental regulations for refrigerants: Regulating the refrigerants primarily deals with capping the GWP of refrigerants which has a direct bearing on abating the direct carbon emissions (end of life and operational leakage). The findings of the market assessment showed that most room air conditioners in the region are equipped with R-410a and the second most common refrigerant gas found is R-22. For refrigerating appliances, R-134a and R-600a are the common refrigerants used, while R-600a is becoming more and more popular. In the EAC region, environmental regulations are available in Kenya, Uganda and Rwanda, whilst in SADC only the Democratic Republic of Congo has not put in place environmental regulations covering refrigerant gases used in both products. Further, three countries, namely Rwanda, Namibia and South Africa have committed to the Kigali Amendment to the Montreal protocol that aims to phase out the production and consumption of HFCs. In addition, Kenya has initiated the process of ratification.

Financial incentives for refrigerators and air conditioners: In both regions, two countries have introduced financial incentives to support the deployment of energy efficient room air conditioners and refrigerating appliances. Seychelles introduced VAT exemption, while Mauritius imposes a 25% levy on energy inefficient products.

Supply chain of refrigerators and air conditioners: The market assessment revealed the existence of manufacturers for refrigerators and freezers in both regions. The bulk of residential refrigerating appliances sold in the two regions are imported from international production facilities. In the SADC region, South Africa plays a significant role in the distribution of residential refrigerating appliances, as most of the household appliance stores found across the region originate from South Africa whereas in EAC most of the refrigerators come from outside of the region. In both regions, there are no manufacturers of room air conditioners; thus, the supply of room air conditioners is characterized by imports from various parts of the world and mainly from China.

Monitoring: The market assessment found that Kenya, Rwanda, Mauritius, Seychelles and South Africa have or are in the process of introducing product registration systems, which can be used to monitor compliant products available for sale in the market. The systems that are in place for these countries are not coordinated or harmonized regionally.

MEPS in the EAC and SADC Regions: Currently, out of the 21 countries in SADC and EAC regions, only seven countries have MEPS in place for either refrigerating appliances or air conditioners (as seen in table 1). In addition, the market assessment showed that the standards are at different levels of implementation, as only four countries have mandatory MEPS in place for refrigerating appliances and only four countries have mandatory MEPS for air conditioners.

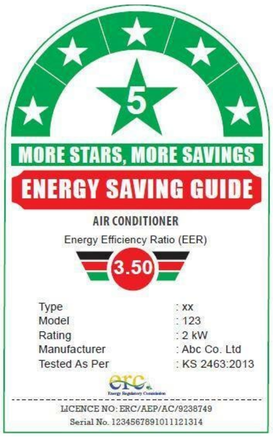
Table 1. Overview of EAC and SADC countries with MEPS

Country/Region	Refrigerating Appliances	Air Conditioners
	EAC	
Kenya	Mandatory (2013)	Mandatory (2013)
Uganda	Voluntary (2011)	Voluntary (2011)
Rwanda	Voluntary (2015)	Voluntary (2015)
	SADC	
Democratic Republic of Congo	X	Mandatory
Mauritius	Mandatory (2017)	X
Seychelles	Voluntary (2015)	Voluntary (2015)
South Africa	Mandatory (2014)	Mandatory (2014)

South Africa has put in place compulsory specification for energy efficiency and labeling of refrigerating appliances and air conditioners (VC9008) [8] and it continues to play a significant role in the distribution of refrigerating appliances and air conditioners in the SADC region. The South African MEPS for refrigerating appliances are more aligned to the EU regulations No. 1060/2010 for energy labeling of refrigerating appliances [9]. South Africa has adopted IEC 62552,2007/SANS 62552 as the performance measurement standard for refrigerating appliances [8]. In the South African context, Energy Efficiency Index (EEI) is used to determine the energy label class for refrigerating appliances. The South African Regulations requires refrigerators and freezers to comply with SANS 941, and shall have a minimum energy efficiency rating of Class B ($55 \leq EEI < 75$) and Class C ($75 \leq EEI < 90$), respectively. Mauritius adopted the European Union energy efficiency label having similar requirements with South Africa's label.

In the EAC region, Kenya and Rwanda have developed energy labels for refrigerating appliances [10], [11]. Both countries have adopted IEC 62552, 2015 as the performance measurement standard. Energy efficiency labels in Kenya are outlined in the Energy (Appliance Energy Performance and Labels) Regulation 2016 that use appliance Star Rating Index (SRI) which is the ratio calculated from the appliance model comparative energy consumption and base energy consumption per annum. Based on the SRI the refrigerating appliances are given a 1-5 stars label with appliances with high SRI having high star ratings. It was established that most of the refrigerating products registered for sale in the Kenya market are rated 1-2 stars (SRI<4.5). Rwanda energy efficiency labels for refrigerating appliances are aligned to the U4E model regulations guidelines which uses the Energy Consumption Index (R) with a minimum R value of 1.

Figure 23. Kenya energy efficiency label



Source: [9]

The Energy Efficiency Ratio (EER, kW/kW) is used for energy efficiency grading of different types of air conditioners in all the countries that have MEPS in the SADC region. The South Africa energy efficiency label was found to be very common for air conditioners throughout the SADC region. The South Africa's standards and labeling requirements elucidated in VC9008 require room air conditioners to have a minimum energy efficiency rating of Class B (Split 3.2 ≥ EER > 3.0, Portable 2.6 ≥ EER> 2.4, and Window 3.0 ≥ EER > 2.8). The minimum EER requirements for wall mounted split air conditioners in Seychelles are equivalent to Class B of South Africa's MEPS requirements. The test conditions applicable to South Africa are as cited in SANS 54511-2, which mirrors EN 14511-2. In the EAC region, air conditioners having Kenya star rating energy efficiency label are compliant to the labeling requirement of Energy (Appliances Energy and Labels) Regulation of 2016. In the Kenyan context, EER is used to determine the number of energy stars for air conditioners. Labels for air conditioners in Rwanda are still under development. Different classes of air conditioners are based on the Rwanda Seasonal Energy Efficiency Ratio (RSEER) and the appliances' rated cooling capacity.

The adoption of energy efficient room air conditioners and residential refrigerating appliances can play a key role in the reduction of energy demand and greenhouse gas emission in both regions. According to the UNEP-U4E Country Saving Assessment, it is estimated the EAC region could save approximately 3.2 TWh (1.8 TWh for air conditioners and 1.4 TWh for residential refrigerating appliances) by 2040. The SADC region could save approximately 9.4 TWh (4.8 TWh for room air conditioners and 4.6 TWh for refrigerating appliances) by 2040 [1].

Technical Notes for residential refrigerators and room air conditioners

Based on the findings of the market assessment, technical notes were developed with the support of the Lawrence Berkeley National Laboratory (LBNL), which include technical recommendations for the MEPS. The aim of the technical notes is to support EAC and SADC's effort to establish and improve energy efficiency standards for both cooling appliances. The notes include an overview of global market and policy trends as well as technical recommendations for a harmonized policy framework across the region. Primarily based on the market assessment and the UNEP-U4E Model Regulation Guidelines the following preliminary recommendations were made for further discussion amongst the EAC and SADC member countries:

- Establish a regionally harmonized energy efficiency standard and compliance infrastructure.
- Establish and harmonize energy efficiency standards and labeling requirements, and test standards aligned with international standards best practices and UNEP-U4E Model Regulation Guidelines by developing an energy efficiency roadmap for cooling equipment.
- Implement energy-efficiency standards that consider low-GWP refrigerants along with improvement of safety standards.
- Establish an appropriate infrastructure for product certification and registration by harmonizing databases regionally and allow data sharing.
- Establish an appropriate infrastructure for testing or verifying energy efficiency performance by exploring testing collaboration opportunities through mutual recognition agreements among governments, and test laboratories in different regions, which mitigate the cost of testing laboratories and strengthen compliance schemes.
- Strengthen the compliance regime.
- Consider adoption of IEC 62552; 2015 standard for refrigerating appliances which is widely used in many countries around the globe, including the EU. Adopting this widely used metric would improve standards and labeling for refrigerating appliances in EAC and SADC countries, while facilitating harmonization with international refrigerator-efficiency efforts.
- Consider setting requirements for energy consumption of refrigerating appliances at an appropriate reference ambient temperature, e.g., 24°C, that could be estimated from energy consumptions measured at low (16°C) and high (32°C) temperatures.
- Consider adopting a seasonal efficiency metric, e.g., the ISO cooling seasonal performance factor (CSPF) metric for air conditioners.

- Combine fixed-speed (non-inverter) and variable-speed (inverter) air conditioner product categories under the same metric so that consumers clearly differentiate between the two and benefit from the energy savings from variable-speed ACs
- For determining the CSPF of fixed-speed air conditioning units, reduce compliance costs by using only one set of test data at full-capacity operation at 35°C, and use another set of data points at 29°C calculated by predetermined equations, which results in a linear relationship with EER, i.e., CSPF = 1.062 × EER with the ISO reference temperature bin hours.
- For variable-speed air conditioner units, determine CSPF while reducing compliance costs by using two sets of test data at full- and half-capacity operation at 35°C and another set of data points at 29°C calculated by predetermined equations, without considering a minimum-capacity operation.
- Consider using only a single reference set of temperature bin hours (e.g., the ISO 16358 temperature bin hours) for CSPF metrics in all EAC and SADC countries to evaluate efficiency performance of air conditioners with energy efficiency standards and labeling requirements.
- Consider additionally using the ISO CSPF metric based on country-specific bin hours of air conditioner use for assessing and informing absolute impacts (energy use, electricity cost, emissions, etc.). The ISO 16358 temperature bin hours could be used for efficiency standard purposes without impacting the relative order of efficiency ratings and reducing compliance costs.
- Update standards periodically to mitigate risk of obsolete technology being deployed in markets without updated standards, as well as reflect benefits of commercially available and emerging technology.

4. Engagement of the Technical Committees

The development of the harmonized MEPS for refrigerating appliances and air conditioners is guided by the principles and procedures for the development and harmonization of harmonized standards prepared by the East African Standards Committee (EACS) and Southern African Development Community Cooperation in Standardization's (SADCSTAN). As guided by the same principles and procedures, Standards Technical Committees have been established at regional and national levels in the two regions. The Technical Committees support the development of regionally harmonized MEPS for refrigerating appliances and room air conditioners and further facilitate the adoption of these at the national level. The Regional Technical Committee comprises of the following stakeholder representatives from each of the Member countries:

- Representative from the Ministry responsible for energy affairs, preferably dealing with energy efficiency.
- Representative from the National Standards Body conversant with the standards formulation process.
- Representative from the Ministry responsible for environmental affairs, preferably from the National Ozone Unit.
- Representative of the Regional Regulator.
- Representative of the Power Pool.

The National Technical Committees comprises the following stakeholder representative as follows:

- Representative from the Ministry responsible for Energy affairs, preferably dealing with energy efficiency.
- Representative from the National Standards Body conversant with standards formulation process.
- Representative from the Ministry responsible for Environmental affairs, preferably from the National Ozone Unit.
- A Representative of the Energy Regulator.
- A representative of the State Electricity Utility.
- Stakeholder Representatives for cooling appliances.
- Manufacturer's/Distributor's representative.
- Private Sector Association representative (refrigeration and cooling expert).
- Consumer Protection association/NGO representative.

The development process for regionally harmonized MEPS in the EAC and SADC regions involves the following seven project stages:

- **The preliminary stage** is a stage at which the National Standards Bodies receive an idea or Preliminary Work Item for a harmonized standard.
- **The proposal stage** is the stage at which the National Standards Bodies receives, and either accepts or rejects a proposal for a new work item proposal.
- **The preparatory stage** covers the preparation of a Working Draft of the harmonized standard.
- **The committee stage** is the stage at which comments from National Standards Bodies are received, consensus is built, and voting is requested for progression of the draft to the Enquiry stage.
- **The enquiry stage** is the stage at which the draft harmonized standard is made available for public comments.
- **The ballot stage** is the stage at which the final draft harmonized standard is circulated to member states for balloting to advance to the next stage.
- **The approval stage** is the stage where EASC or SADCSTAN approves the final draft harmonized standard.

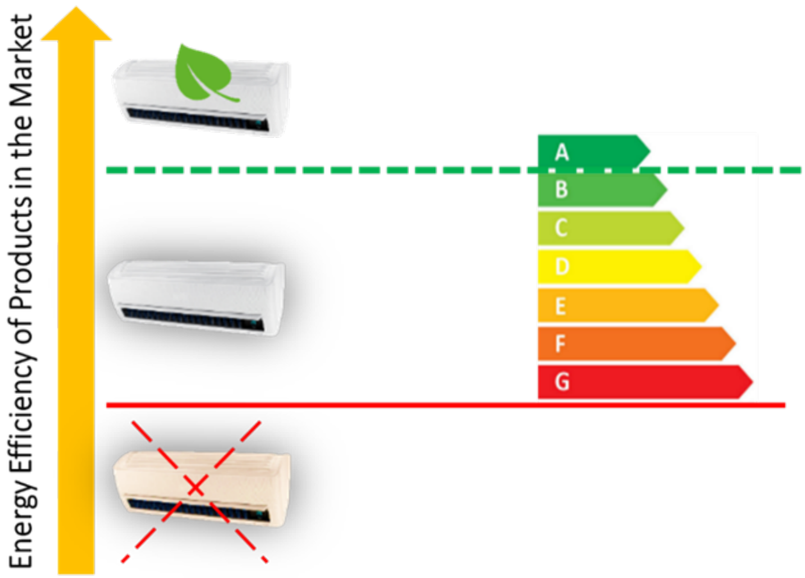
As mentioned above, the work of the Technical Committees commenced with an inception meeting in June 2020 where the market assessment findings and technical notes were presented to the two regional Technical Committees. With the assistance of LBNL, the draft MEPS for both appliances were produced and presented to the Regional Technical Committees in another subsequent meeting. These drafts are considered as working drafts in both regions. Both regions are now at the committee stage in terms of the standard development process which involves consultation with the National Technical Committees. This process has started with meetings to introduce the draft MEPS to national stakeholders and further solicit comments. After the conclusion of this process, the draft MEPS will be revised according to the comments received and the revised MEPS will be presented to the Regional Technical Committees for consideration and approval to move to the next stages of the development process.

5. Importance of MEPS and labelling

MEPS are one of the fastest and most effective policy options to move a market to more energy efficient products. Today, at least about 130 countries have adopted or are currently adopting MEPS to phase out inefficient products from their markets. When countries are implementing MEPS, they often do that in parallel with the implementation of labels as they guide the consumer to procure more energy efficient products. The functionality of MEPS and labels is shown in figure 3 in a glance. When MEPS are implemented, models not meeting the minimum efficiency requirements may no longer be imported or sold after the effective date of implementation of the standard.

It is crucial to conduct a careful market analysis before setting the policies as it is important to set them at the right level. If MEPS levels are set too low, they might not have any effect on the market and inefficient products continue to circulate. And on the contrary, if MEPS are set at a too high level, they might influence the market in a negative manner, such as by targeting only air conditioners that are not available in the market of the country. MEPS that are set at a correct level leave out only efficient products on the market that are already available and which must be affordable by consumers. In addition, well designed MEPS encourage manufacturers to improve the efficiency of their products and/or importers to merchandise higher efficiency products.

Figure 3. Functionality of MEPS and labels



Further, energy efficiency labels inform consumers about the efficiency of the products that are left on the market after introducing the MEPS. The labels are displayed on the product and typically contain an energy-efficiency classification, such as from A-G in the figure or also in other formats as for example with stars. The product is then evaluated along this classification and consumers can easily identify if the product they wish to purchase is among the higher or less efficient range. If these policies come along with consumer awareness campaigns to inform for example that a less efficient air conditioner consumes more electricity and thus electricity bills are higher, consumers are even more encouraged to invest in the higher efficient options as this investment often pays off over the lifetime of the air conditioner.

In addition, it makes sense to harmonize the MEPS and labels with those of neighboring countries or the whole region. If several countries, such as the countries of the EAC and SADC regions, decide to implement the same policies this avoids dumping grounds. A dumping ground often arises when one country has less stringent regulations and less efficient products that are forbidden for sale in other countries can still be sold in the particular country. If the whole region has the same level of MEPS these situations are avoided. Moreover, the same level of MEPS and labels pushes the economy as manufacturers and importers only need to comply with one set of regulations. To comply with MEPS, the products must be tested by independent laboratories to comply with the regulation. If these testing standards, that typically come in hand with the MEPS, are harmonized it is more cost-effective for manufacturers and/or importers as the testing needs to be done only once.

As mentioned above, regarding refrigerators and air conditioners an additional point to energy efficiency must be considered, which is the climate-friendliness. Air conditioners and refrigerating appliances contain refrigerants, which are often harmful for the climate as they contain high GWP or Ozone Depleting Potential (ODP) refrigerants. This is important, as the capacity of these refrigerants to heat up the atmosphere is a lot greater than carbon dioxide. Particularly in markets of developing countries air conditioners and refrigerators with high GWP and ODP are circulating, therefore it is crucial to not only target the energy efficiency of these products but also the refrigerants. MEPS for cooling products should therefore also contain a clause on the maximum allowed GDP and ODP levels. The EAC SADC project is for example proposing a maximum allowed ODP of zero and GDPs of 20 for refrigerators and 150 for self-contained and portable air conditioners as well as 750 for ductless split products. These levels are in line with the U4E model regulation guidelines (further details are described below).

6. Model regulations on air conditioners and refrigerators

The U4E Model Regulation Guidelines provide voluntary guidance for governments in developing and emerging economies that are considering a regulatory or legislative framework. They contain essential elements, including product scope, definitions, test methods, minimum efficiency levels and a set of minimum performance requirements, along with market surveillance measures which ensure consumers can purchase quality efficient products with confidence. In developing the guidelines for the cooling products, U4E and its partner LBNL consulted dozens of experts from various sectors and global regions to assess best practices and new developments. Within the guidelines, the aim has been to balance more ambitious energy performance against limiting adverse impacts on upfront costs and the availability of products.

The Model Regulation Guideline for residential refrigerators and room air conditioners include both a minimum energy efficiency floor and limits on the GWP of refrigerant gases (GWP of 20 for residential refrigerators, 150 for self-contained air conditioners and 750 ductless split system air conditioner). In addition, the guidelines refer to commonly used international standards such for room air conditioners as International Organization for Standardization (ISO) 16358 and ISO 5151 for testing and seasonal efficiency metrics on room air conditioners. For residential refrigerators, the Model Regulation Guidelines refers to IEC 62552:2015 for testing and measuring energy consumption.

For more information on the Model Regulations Guidelines for air conditioners and refrigerating appliances, please consult both the Model Regulations themselves and the detailed Supporting Information documents through the link indicated in the related source [9].

7. Proposed MEPS and labelling

This section delineates the proposed MEPS for air conditioners and refrigerating appliances in the SADC and EAC countries. The market assessment report in both the regions served in benchmarking the energy efficiency standards of household refrigerating appliances and air conditioners available in the current market. The MEPS are formulated factoring the technological advancements, affordability and availability of the products, skilled personnel and testing infrastructure capacities.

If not explicitly stated otherwise, the source for the text of this chapter are the regional MEPS and labeling documents, which are not indicated in the bibliography as these are working documents. The documents can be provided upon request.

Air Conditioners

The proposed MEPS cater to both air cooling and heating (heat pumps) products and are applicable to fixed capacity, two-stage capacity, multi-stage capacity, and variable capacity units used in the domestic sector. Hence, the cooling/heating capacity of the products is capped at 16 kW (4.55 TR). The global market is witnessing the increasing use of variable speed units (also referred as the inverter type) which are replacing the fixed speed type. The Cooling Seasonal Performance Factor (CSPF) as described in ISO 16358 [12] helps evaluate both the fixed speed and inverter units and is hence employed as the energy efficiency metric to define the MEPS for air conditioners and heat pumps. The test methods and reference standards for the energy efficiency calculations are summarized in table 2.

Table 2. Reference Standards for Test Methods and Energy Efficiency Calculations

Test Methods	Reference Standards
Temperature and humidity conditions and default values for cooling efficiency test at T1 for moderate climate *	ISO 16358-1:2013 Table 1
Test methods for cooling efficiency	ISO 16358-1:2013 Chapter 5
Cooling efficiency calculations	ISO 16358-1:2013 Chapter 6

Temperature and humidity conditions and default values for heating efficiency test	ISO 16358-2:2013 Table 1
Temperature and humidity conditions and default values for cooling efficiency test at T3 for hot climate	ISO 16358-1:2013/Amd 1:2019 Table F.1
Test methods for heating efficiency	ISO 16358-2:2013 Chapter 4
Heating efficiency calculations	ISO 16358-2:2013 Chapter 5
APF calculation	ISO 16358-3:2013 Chapter 5

The proposed MEPS are planned for implementation in a phased manner to allow market preparedness and administrative requirements. Furthermore, this transition time provides an opportunity to enhance the capacity building of relevant stakeholders from industry and laboratory personnel, etc. The initial MEPS for a 4.5 kW product is pegged at 4.5 CSPF accounting the local conditions and the latter MEPS at 6.1 CSPF which are in line with the international market trends. The summary of the proposed MEPS is represented in table 3 (a). Four levels of labels as shown in table 3 (b) are proposed for both air conditioners and heat pumps viz. Low, intermediate 1, intermediate 2, and high respectively.

Table 3 (a). Minimum CSPF and APF Requirements for Air Conditioners

Category	CSPF (MONTH DATE, 2023)*	CSPF (MONTH DATE, 2026)*	APF (MONTH DATE, 2023)*	APF (MONTH DATE, 2026)*
CC≤ 4.5 kW	4.50	6.10	3.70	5.00
4.5 kW < CC ≤ 9.5 kW	4.20	5.10	3.30	4.00
9.5 kW < CC ≤ 16.0 kW	3.80	4.50	3.00	3.60
Outdoor Temperature Bin Hours	(Table 3 in ISO 16358-1)		(Table 3 in ISO 16358-1) (Table 3 in ISO 16358-2)	

Table 3 (b). Labelling Requirements for Air Conditioners

Category	Low	Intermediate 1	Intermediate 2	High
CC≤ 4.5 kW	4.50 ≤ CSPF < 6.10	6.10 ≤ CSPF < 7.10	7.10 ≤ CSPF < 8.00	8.00 ≤ CSPF
	3.70 ≤ APF < 5.00	5.00 ≤ APF < 6.10	6.10 ≤ APF < 7.10	7.10 ≤ APF

4.5 kW < CC ≤ 9.5 kW	**4.20 ≤ CSPF < 5.10**	**5.10 ≤ CSPF < 6.40**	**6.40 ≤ CSPF < 7.60**	**7.60 ≤ CSPF**
	3.30 ≤ APF < 4.00	**4.00 ≤ APF < 5.20**	**5.20 ≤ APF < 6.40**	**6.40 ≤ APF**
9.5 kW < CC ≤ 16.0 kW	**3.80 ≤ CSPF < 4.50**	**4.50 ≤ CSPF < 5.80**	**5.80 ≤ CSPF < 7.10**	**7.10 ≤ CSPF**
	3.00 ≤ APF < 3.60	**3.60 ≤ APF < 4.70**	**4.70 ≤ APF < 5.80**	**5.80 ≤ APF**
Outdoor Temperature Bin Hours	**(Table 3 in ISO 16358-1)** **(Table 3 in ISO 16358-2)**			

CC: Cooling capacity; CSPF: Cooling seasonal performance factor; HSPF: Heating seasonal performance factor;

APF: Annual performance factor; *Proposed timeline

Residential refrigerating appliances

The MEPS proposed under the residential refrigerating appliances include refrigerators, freezers and refrigerator-freezer products. It includes both frost-free and direct-cool technology products. The scope of the MEPS is however limited to products between 10 litres and 1,500 litres of capacity. The energy consumption index 'R' defined as the ratio of the maximum annual energy consumption (calculated) to (experimentally evaluated) annual energy consumption is used as the energy efficiency metric to describe the MEPS for all the three refrigerating categories which is per IEC 62552 [13].

Table 4. Maximum Annual Energy Consumption (AEC_{Max})

Reference Ambient Temperature	Product Category	AEC_{Max} (kWh/year)
24°C	Refrigerators	0.163AV+102
	Refrigerator-Freezers	0.222AV+161
	Freezers	0.206AV+190

where AV is Adjusted Volume, as calculated per Equation 1

The MEPS are based on the following equations:

Equation 1. Adjusted Volume (AV) = $\sum_{i=1}^{n}(V_i \times K_i \times F_i)$

where V_i is volume in *i*th compartment, K_i is volume adjustment factor as calculated per Equation 2 and rounded to two decimal places, and F_i is frost adjustment factor.

Equation 2. K= $(T_1-T_c)/(T_1-T_2)$

T_1 is reference ambient temperature, T_2 is temperature of fresh-food compartment (4°C), and T_c is temperature of the individual compartment concerned.

The Annual Energy Consumption (AEC), is calculated per Equation 3, shall be less than or equal to Maximum Annual Energy Consumption (AEC_{Max}).

Equation 3. AEC = EC_T * (365/1000) in kWh per year

where EC_T is energy consumption in Wh per 24 hours based on ambient temperature T, as calculated per Equation 4 and rounded to nearest integer.

Equation 4. EC_T = a * $E_{daily,16}$ + b* $E_{daily,32}$ in Wh per day

where $E_{daily,16}$ is energy consumption measured at ambient temperature 16°C and $E_{daily,32}$ is energy consumption measured at ambient temperature 32°C, and a,b have coefficient values of 0.5 at 24°C reference ambient temperature in accordance with IEC 62552-3.

Similar to air conditioners, the refrigerating appliances MEPS implementation is also planned in a phased manner as represented in table 5 to allow market readiness and streamlining administrative requirements. The initial MEPS are pegged at 1 (R) and the latter MEPS at 1.25 (R) CSPF aligning with the technological advancements. Four levels of labels as shown in table 6. Low, intermediate 1, intermediate 2, and high respectively are proposed for all refrigerator types.

Table 5. Minimum R Requirements for Refrigerating Appliances

Category	R (MONTH DATE, 2023)	R (MONTH DATE, 2026)
Refrigerators	1.00	1.25
Refrigerator-Freezers	1.00	1.25
Freezers	1.00	1.25

Table 6. Labelling Requirements for Refrigerating Appliances

Category	Low	Intermediate 1	Intermediate 2	High
Refrigerators	1.00 ≤ R < 1.25	1.25 ≤ R < 1.50	1.50 ≤ R < 1.75	1.75 ≤ R
Refrigerator-Freezers	1.00 ≤ R < 1.25	1.25 ≤ R < 1.50	1.50 ≤ R < 1.75	1.75 ≤ R
Freezers	0.75 ≤ R < 1.00	1.25 ≤ R < 1.50	1.50 ≤ R < 1.75	1.75 ≤ R

As mentioned above, Rwanda, Namibia and South Africa have ratified the Kigali amendment to the Montreal protocol while Kenya is in the pipeline of adoption. The proposed MEPS also provide the upper threshold limits on the GWP and the ODP of the refrigerants which are outlined in table 7.

Table 7. Requirements for Refrigerant Characteristics (numbers shown are upper limits)

Category	GWP	ODP
Self-Contained & Portable Systems	150	0
Ductless Split System	750	0
All refrigerator types	20	0

8. National Consultations

As mentioned above, the draft MEPS were first presented to the Regional Technical Committees in both regions with the aim to sensitize the committee members and transmit the MEPS to national stakeholders for consideration.

Subsequent to the Regional Technical Committee meetings, national consultations commenced in the SADC region with kick off meetings with the aim of introducing the draft MEPS to national stakeholders. During each of the national meetings the MEPS and labels were presented again in a power point presentation and were discussed during the meeting with the participants, which mainly came from energy ministries, standards bodies and ozone units. The process of the national meetings began in the SADC region in October 2021 and was concluded in April 2022, table 8 shows an overview of the countries and dates on the national consultations. In total 12 meetings were held in the SADC region, four countries (Angola, Comoros, Mozambique and Tanzania) did not respond to the request for a meeting. In parallel, the national stakeholders were invited to make comments and input on the draft MEPS based on the country's needs and policy direction. This exercise was led by the National Standards Bodies in collaboration with the Ministry responsible for energy affairs.

The national consultation meetings were particularly important as they did also discuss currently policies in place and revealed the dynamic of the markets in the region further. Especially the exchange with South Africa was of critical an importance as the country is a major player in the region. During this meeting, which was held on 23rd February 2022, the planned MEPS for refrigerators were shared by country officials. Based on this exchange the stringency levels for MEPS and labels were updated to be aligned with South Africa's plan. The level was in that context lifted by R=0.25 to R=1 for year 2023 and R=1.25 for year 2026, table 5 and 6 in chapter 7 show already the updated MEPS and labels.

Table 8. National Consultation Meetings in SADC (status May 2022)

Member State	Date of Meeting
Botswana	Held on 21st Jan 2022
DRC	Held on 27th Jan 2022
Eswatini	Held on 22nd Nov 2021
Lesotho	Held on 28th Jan 2022
Madagascar	Held on 10th March 2022
Malawi	Held on 9th Dec 2021
Mauritius	Held on 28th Oct 2021

Namibia	Held on 13th April 2022
Seychelles	Held on 18th Oct 2021
South Africa	Held on 23rd Feb 2022
Zambia	Held on 14th Jan 2022
Zimbabwe	Held on 7th Dec 2021

In parallel, also the EAC region was offered to hold national consultations. However, the regional standards body is understaffed, and bureaucratic challenges thus are holding back the start of the national consultations. In addition, budget restraints at EACREEE are adding to the challenges in the region.

9. Current status and next steps

In the SADC region the national consultation process was concluded as based on SADCSTAN requirements as the majority of the members participated in the national consultations. Thus, a regional consultation meeting was held on 29th April 2022 to go through the comments that were received by the member countries and to present the updated MEPS and labels. The meeting, which was attended by 14 SADC countries, concluded with the request for additional comments on the updated MEPS. The updated MEPS did undergo the mentioned change on the refrigerator's stringency levels and some additional changes in wording which do not impact the technical details of the documents. Both documents remain working documents until the deadline for further comments ends in the SADC region on 20th May 2022. In parallel, until this deadline also the four remaining countries which did not undergo national consultations (Angola, Comoros, Mozambique and Tanzania) are currently offered again to conduct a meeting.

In-terms of the next steps in the implementation of the project, the following is planned:

- Consolidate additional comments received from all countries in both regions and produce revised draft MEPS (if needed).
- Solicit approval of the revised final draft MEPS by following the SADCSTAN's principles and procedures for harmonization of harmonized MEPS in the two regions.
- Upon approval of the final draft MEPS, countries can begin the national adoption process.

The national adoption process is in eight countries also being advanced on the refrigerator's side by national Green Climate Fund (GCF) projects, which are implemented in Botswana, Eswatini, Lesotho, Malawi, Tanzania, Zambia and Zimbabwe. The aim of the projects is among others to develop national standards on residential refrigerators and thus overlaps partly with the regional project. U4E is involved as a technical partner within these project and coordinates in this context closely with the implementers which are represented by SACREEE, BASE, ICA, Clasp and Pegasys to align the regional with the national policy development.

Also, in the EAC region the process and requirements of EACS are similar to SADCSTAN. In that context a similar approach is planned once the national consultations can be concluded.

10. Conclusion

A regional MEPS and labels development is a lengthy and bureaucratic process as it involves a wide range and numerous stakeholders which need to achieve a common agreement. However, the process bears its fruits as regional MEPS and labels have multiple benefits, such as a reduction of trade barriers, an improved quality of the appliances and others. Ultimately, the harmonized policies reduce the environmental impact of the energy consumption for a region, while at the same time boosting the economy.

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Interventions for Improved E-Waste Management in Sub-Saharan Africa: Case Studies from the Global LEAP Awards Solar E-Waste Challenge

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Abstract

Over the past decade, hundreds of millions of people in off- and weak- grid environments have gained access to clean energy thanks to the rapid expansion of off-grid solar products and services. Yet, the proliferation of solar e-waste poses a threat to the health and environment of the very people benefiting from off-grid energy services. Across sub-Saharan Africa, infrastructure for e-waste management is either nascent or undeveloped, leaving end-users with limited to no options. Most consumers deal with their end-of-life solar products by storing, dumping, burning or disposing of them in water bodies or latrines. As solar sales grow, a sustainable solution for e-waste management must be developed.

To stimulate innovations and collaboration for off-grid solar e-waste management, the Efficiency for Access Coalition launched the Global LEAP Awards Solar E-Waste Challenge in 2019. The Challenge selected eight companies - off-grid solar, recyclers and waste management companies from five sub-Saharan African countries - to test different aspects of e-waste collection and disposal, including recycling, repair and refurbishment, take-back and collection, awareness raising and incentives. This paper aims to share the good practice that emerged from these projects, with the spotlight on Kenya, as the largest off-grid solar market on the continent and the implementing country for half of the projects. The paper explores key interventions so that other companies can replicate the successes and avoid some of the pitfalls.

Introduction

Over the past decade, more than 180 million off-grid solar products have been sold globally, benefitting more than 420 million people.[200] The most common solar products available in the off-grid market include: a) pico-solar products (PSP) or small, low-cost solar lights; b) solar home systems (SHS) or a combination of solar panels and a battery that can power multiple lights or small appliances; and c) solar-powered appliances, including televisions, radios, refrigerators and other small USB-powered equipment.[201]

While solar products improve the quality of life for consumers and their households, every product will eventually stop working. When e-waste is not properly disposed, if exposed to heat or damaged, toxic chemicals are released and damage human and environmental health; toxic substances – especially in batteries – can seep into groundwater, affecting land and sea animals, disrupting crop development, polluting freshwater sources, and contributing to air pollution. In Africa, collected and properly recycled e-waste (not just solar) is reported to be 4% in Southern Africa, 1.3% in Eastern Africa and close to 0% in other regions[202]. This is attributable to the fact that formal recycling infrastructure is underdeveloped or non-existent. In Africa, there are e-waste recyclers in Ghana, Kenya, Nigeria, Rwanda and South Africa, but due to the complexity of materials, some components must be shipped to other continents for treatment. Additionally, where facilities may be available, they may not meet the required international health, safety and operational standards such as ISO 45001, ISO 14001 and ISO 9001. Although solar e-waste makes up an estimated 0.5% of total e-waste on the continent, as the industry grows, so will the quantities of solar e-waste.

Since 2014, various studies by industry and academia have provided insights into the nature of off-grid solar e-waste, exploring strategies to effectively reduce and manage end of life (EOL) products.[203] However, there are considerable challenges to e-waste management in off-grid communities across sub-Saharan Africa. The industry is still relatively young and serves a market with nascent or immature waste management

[200] Lighting Global et al, Off-Grid Solar Market Trends Report 2020 (March 2020)
[201] Efficiency for Access, Appliance Data Trends 2021 (January 2021)
[202] Global E-Waste Statistics Partnership(globalewaste.org)

[203] GOGLA, GOGLA Industry Opinion on Lifecycle and Recycling (2014).

infrastructure, where related legislation is in its infancy. Low volumes of collected waste and high treatment costs also make it difficult to implement effective e-waste management strategies.[204]

In 2019, the Efficiency for Access Coalition launched the Global LEAP Awards Solar E-Waste Challenge with funding from USAID, DFID (now FCDO) and Shell Foundation. The Challenge aimed to catalyse the development of sustainable approaches to off-grid solar e-waste management by addressing barriers to take-back and collection, recycling, repair and consumer awareness raising.

The Challenge made US $1 million available in grants of up to US $200,000. The grants intended to support:

- Distributors of off-grid solar products seeking to pilot and implement EOL programmes, which would fill the critical and data gaps regarding EOL product management, and address key logistical challenges related to take-back and collection.
- Recycling and e-waste management companies looking to expand business activities in the off-grid sector and strengthen operational processes at e-waste processing facilities in order to increase solar e-waste recycling capacity across sub-Saharan Africa.

The Challenge received 159 applications to implement projects in 49 countries across sub-Saharan Africa. Eight awardees were selected, including five off-grid solar distributors (d.light, ENGIE Energy Access, Solibrium, Sunny Money and WeTu) and three recycling companies (Enviroserve Rwanda, Hinckley Recycling and WEEE Centre) with projects in Kenya, Uganda, Rwanda, Zambia and Nigeria.

Over the 12-month implementation period, the awardees-built e-waste processing facilities, purchased crucial equipment, explored repair and refurbishment possibilities, conducted consumer-awareness campaigns across a variety of platforms, and implemented a number of different take-back schemes. They collectively amassed more than 250,000kg of off-grid solar waste, a small fraction of the total levels (estimated to be around 51 kilotons for Kenya in 2019[205]), but enough to identify key lessons about the design and implementation of e-waste management programmes.

This paper illustrates how to improve access to waste by awareness raising and incentivization. It also presents considerations for setting up effective takeback and collection schemes and key requirements for sustainable recycling. Additionally, it gives new insights on gender inclusion and the cost of managing e-waste in the off-grid sector. Finally, it provides recommendations for a wide array of stakeholders in the sector, including investors, companies and governments. The focus on the Kenyan landscape illustrates opportunities for implementing successful e-waste management programs in mature off grid solar markets but also presents foundational elements to nascent markets as well.

Methodology

The Challenge developed a detailed Learning & Coordination Framework (L&C) to collect insights from the eight awardees. The goal of the framework was to assist awardees to analyze their projects, gain insights to scale up the initiatives, facilitate the establishment and development of partnerships among the awardees along with external actors, and provide market insights to sector stakeholders. It included four approaches to gather data on the projects: quantitative metrics, qualitative quarterly reports, product sampling, and coordination meetings.

1. Quantitative Metrics: The Challenge developed a list of over one hundred metrics used to track and evaluate the projects. The metrics were categorized by key themes:
    - Awareness
    - Takeback and collection
    - Repair
    - Refurbishment
    - Recycling
    - Capacity building
    - Partnerships and collaboration

[204] Efficiency for Access, Global LEAP Awards Solar E-Waste Market Scoping Report (October 2019)

[205] Global E-Waste Statistics Partnership country sheet for Kenya, 2019 (retrieved from: https://globalewaste.org/statistics/country/kenya/2019/) and DfID, Electronic waste (e-waste) impacts and mitigation options in the off-grid renewable energy sector, (August 2016)

- Second battery life

To facilitate simplified aggregation and analysis of the data, the awardees submitted this data through an online tool. The Challenge liaised closely with awardees to carry out data quality checks and prepared cumulative outputs.

2. Qualitative quarterly submissions: The Challenge developed a reporting template to track overall, progress of awardees. The templates captured information on overall progress, risks, challenges and GESI (Gender and Social Inclusion) indicators. The awardees submitted these reports on a quarterly basis during the project implementation period.

Table 1. Product sampling findings

Most represented brands	
Brand X	41%
Brand Y	36%
Unbranded	11%
Item type	
Lantern	64%
PSP	31%
SHS	5%
Condition	
Good	7%
Ok	9%
Poor	76%
Very poor	9%

3. Product Sampling: At the end of the project period, the awardees sampled 20% of the e-waste and reported information on the item, brand, model and condition. The aim was to gain insights into the makeup of the collected e-waste. The Table 1 shows one of the company product sampling findings.
4. Coordination Calls: The Challenge hosted quarterly coordination calls with the companies to focus on cross cutting themes identified in the quarterly report submission review. The themes included awareness creation, incentives, informal sector engagement and second life batteries. The coordination calls allowed awardees to provide updates on their projects and share any arising challenges or best practices.

From the substantial data collected, a set of standardized key performance indicators (KPIs) were established to track and measure industry-wide progress in EoL management, support partnerships with recyclers and enable adoption across sector support programmes. The KPIs include:

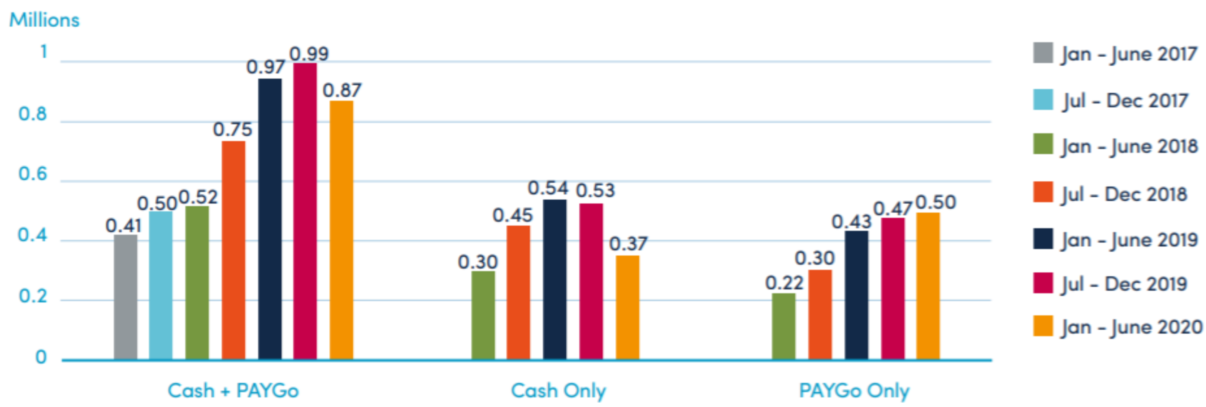
- Weight (Kg) of waste collected
- Weight (Kg) of waste recycled

- Cost of incentive (US$)
- Cost of transport (US$)
- Cost of treatment (US$)
- FTEs employed in e-waste management

Off-Grid Solar Market Status, A Case Study on Kenya

From 2017 to 2019, off-grid solar revenues grew rapidly at 30 percent per year, while sales volumes grew at 10 percent annually[206]. Growth can be linked the World Bank Lighting Africa project that launched in 2010. Kenya leads solar home system (SHS) sales in Africa,[207] this trend can be attributed to a favourable regulatory environment, government support, and the adoption of innovative technologies and business models such as the pay-as-you-go (PayGo) model.[208] There are 56 leading companies in the off-grid solar ecosystem in Kenya[209] and an estimated 10 million Kenyans use off-grid lighting solar products, nearly ten times increase over the past decade. Additionally, since 2019, there has been a steady increase in the sales of off grid solar appliances such as refrigerators televisions and fans.

Figure 1. Evolution of Volume of Lighting Products Sold Since 2017 (Source GOGLA)



The rapid diffusion of off-grid solar products and appliances means that solar e-waste levels have increased. Pico solar products (PSP) and solar home systems (SHS) have average life spans of three and five years respectively.[210] In Kenya alone, 3-4% of the 55,000 tons of total recorded e-waste produced in 2017 was from PSPs and SHSs. Many customers live far away from urban areas or service centres where they can take broken or EoL products, they also often believe that the products hold intrinsic value. Instead, consumers often either store or practice unsafe disposal including burning, burying or discarding the products at home[211] due to a lack of awareness of proper disposal methods.[212] At the national level, recycling infrastructure is insufficient so the informal sector steps in to process waste locally. There is a vibrant market for metal, plastics and lead acid batteries in Kenya, printed circuit boards, lithium-ion batteries and solar panels are exported outside the continent for treatment.

E-waste management activity occurs under a variety of regulatory systems across sub-Saharan Africa. The Kenyan government is supportive of the off-grid solar industry and has instituted policies such as a waiver of VAT and tariffs on solar photo-voltaic (PV) products. Kenya also has an e-waste strategy that provides a roadmap in e-waste management, including extended producer responsibility (EPR) to strengthen the polluter

[206] Lighting Global, GOGLA, and ESMAP, Off-grid Solar Market Trends Report 2020 (March 2020)
[207] Power Africa. Off Grid Solar Market Assessment, Kenya, 2019
[208] Efficiency for Access. Global LEAP Awards Solar E-Waste Market Scoping Report (October 2019)
[209] https://www.asokoinsight.com/content/market-insights/kenya-solar-power-players
[210] Magalini, F., Sinha-Khetriwal D., Rochat D., Huismann J., Munyambu S., Oliech J., Nnorom I.C., and Mbera O. Electronic Waste (e-Waste) Impacts and Mitigation Options in the Off-Grid Renewable Energy Sector, August 2016.
[211] Efficiency for Access. Global LEAP Awards Solar E-Waste Market Scoping Report, October 2019
[212] CDC. How are Off Grid Solar Customers in Kenya Managing their Electronic Waste

pays principle.[213] The Kenyan EPR legislation is in the final stages of approval, it will introduce new obligations for producers of electronic goods, therefore impacting the way e-waste is handled and regulated.

Results and Key Findings

CLASP and GOGLA analyzed qualitative and quantitative data submitted by the eight companies and identified key trends that other companies and e-waste stakeholders can implement to pilot best practice in off-grid solar e-waste management.

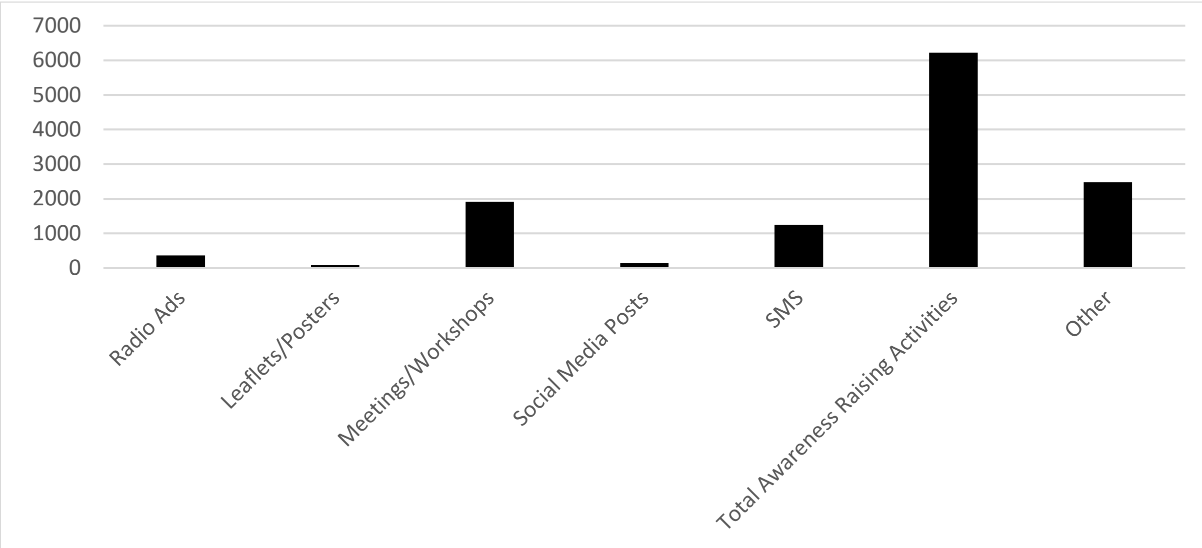
Improving Access to Waste: Awareness Raising & Incentivisation

Awareness Raising

Obtaining EOL e-waste products is a key challenge for companies and e-waste facilities. For off-grid solar products – as with all consumer electronics – the journey from consumption to disposal is complex. It can include periods of repair, reuse and repurposing, as well as "hibernation" during which a broken product is stored at home. Consumers are often unaware of the value of and risks posed by e-waste products at end-of life, or the recommended means of disposal. They also tend to develop an emotional attachment to objects that enter their homes and enrich their lives.[214]

The success of any take-back scheme depends on building consumer awareness of the initiative, as well as incentivizing consumers to relinquish these waste products. The key to a sustainable business model is doing this cost-effectively to add value for the company. Activities undertaken by the awardees are estimated to have reached more than six million people. The awardees reported their awareness raising efforts, methods of communication included word of mouth, SMS and social media, radio and TV campaigns, leaflets and roadshows. They found that word of mouth and radio ads had the best results in terms of driving consumers to collection points to bring in their solar e-waste or to ask clarifying questions.

Figure 2. Total consumer awareness raising activities based on data from the eight awardees



The key lessons on awareness raising are summarized below:

- **Integrate e-waste consumer awareness raising activities into existing communications channels.** Companies should consider which existing networks and channels could support messaging on e-waste take-back and collection schemes. For example, companies using a community-based sales model could train sales agents on e-waste messaging, while companies promoting sales through radio advertisements could use this channel for e-waste related content.

[213] Kenya Ministry of Environment, Kenya E-Waste Management Strategy final draft (January 2019)
[214] Cross, Jamie and Murray, Declan, The afterlives of solar power: Waste and repair off the grid in Kenya (October 2018)

- **E-waste communications campaigns are as nuanced and varied as their target markets.** Each of the eight projects were implemented in vastly different markets, cultures and locations. The success of a campaign in one location does not guarantee that the same campaign would work in another county, region or country. For example, d.light ran radio advertisements in Kenya that were very successful in driving people to their collection points. In Zambia, SunnyMoney also ran radio advertisements and when asking customers how they had heard about the take-back and collection schemes, no one mentioned they heard through the radio advertisements.
- **Take-back schemes provide an additional customer touchpoint that can support customer retention**, help acquire new customers and strengthen brand recognition in the target market. Integrating e-waste messaging into wider communications strategy can therefore add value for a company, as well as mitigate against the cost of e-waste.
- If seeking new communications channels or promoting e-waste management in new markets, conduct a market assessment prior to launching a campaign. This allows companies to target resources towards channels that will yield the greatest benefits. A market assessment should also establish the level of stakeholder understanding and awareness of e-waste. Do not make assumptions about what consumers do and do not know.
- Ask customers returning products how they heard about the take-back or incentive scheme. This feedback allows companies to better target their communications efforts.

Figure 2. A d.light advertisement (Kenya) for their take-back and incentive scheme. 'Has your solar product gotten old and stopped working? Don't worry. Bring it to d.light and get a 50% discount on a new S3 light.' (Source d.light)

Despite significant consumer awareness raising efforts, volumes of returned e-waste from consumers remained lower than expected. Awareness of disposal options and of the risks of e-waste were often not enough for consumers and other stakeholders to return faulty or EoL products to collection centres. Incentives were the real driving factor.

Incentives

Consumers often expect to receive financial incentives to give up or return broken products—this is especially true for products of high sentimental or monetary value. The average cost of incentive for returned EOL products was US $1.17. Vouchers offering discounts against new products were the most common incentive, followed by cash and merchandise. Awardees found that successful incentives must meet three basic criteria:

- **They must be effective.** An effective incentive is one that motivates customers to bring their faulty or EoL products to a collection point. D.light in Kenya offered a 100 ksh ($0.90 USD) discount on a new solar light – this was an effective way to encourage customers to bring in their old waste to receive a new light.

- **They must be useful.** A useful incentive offers a tangible benefit to customers (such as a replacement product or discount voucher). Solibrium Solar offered larger discounts (close to $30 USD) on a new solar home system if customers returned old systems. This was useful given customers needed a replacement for their old/EoL SHS.
- **They must be sustainable.** A sustainable incentive can be implemented beyond the life of the pilot and will not affect the affordability of new products offered by the company.

The key lessons from piloted incentive schemes are summarized below:

- **Pilot different types and values of incentives** to identify the most sustainable and effective option in terms of number/amount of products returned. Many of the projects piloted different types of incentives (cash, discounts, and vouchers) to identify which yielded the best response from consumers.
- **Give vouchers long redemption periods** to account for seasonal incomes and ensure consumers can use the vouchers when it suits them best.
- **Wait until the customer is willing to give up a product for free** rather than try to buy it when there is still a perceived value. Customers are hesitant to relinquish products with perceived value. Build this "hibernation period" into waste forecasts, expectations and messaging.
- **Incentivize staff.** Staff members, particularly field agents, were often unwilling to participate in e-waste collection activities without incentives.

Figure 3. WeTu clean 'Water ATMs' in Homa Bay, Kenya

In Western Kenya, WeTu piloted a scheme offering one of three incentives that could be redeemed with a range of points correlating with returned e-waste (3 points per kg of e-waste). One of the incentives was free water at the clean 'water ATMs,' customers could collect 20 liters for 3 points.

Awareness raising and incentives should be implemented together to yield the best results. A consumer awareness campaign should advertise the incentive and take-back scheme, encouraging customers and other stakeholders to bring back their EoL products to a collection point to exchange for a small discount or other relevant product or service that has perceived value to the consumer.

Designing Effective Take-Back & Collection Operations

Each of the eight awardees carried out take-back or collection of off-grid solar waste. The table below describes the three different models for take-back ad collection of off-grid solar products.

Table 2. Take-back and collection models

Take-Back Scheme
An initiative organized by a manufacturer or distributer to collect used, end of life products or components from consumers to either a) reintroduce them to the market through repair and refurbishment or b) ensure that they are safely and appropriately recycled or disposed of.
Third Party Collection
An activity to collect and process e-waste carried out by a third party such as national WEEE recycling facility, or a Producer Responsibility Organization (PRO) acting on behalf of the original equipment manufacturer. Retail outlets, filling stations or government agencies' buildings are also possible options for collection.
Informal Sector
Covers many different types of actors including informal repair shops (often known as 'fundi'), recyclers, or collectors to cover an entire informal waste-management process. E-waste in this stream often ends up either in informal land-fill or being burnt so that components can be extracted – posing risks to both the environment and health of those involved.

Source: GOGLA's E-waste Toolkit[215]

Off-grid solar companies often have extensive logistics networks across hard-to reach geographies to ensure customers can buy new solar products. The implementation of reverse logistics should be seen as an extension of existing company dispersed logistics. Many companies have well-established operations and reverse logistics to deal with in-warranty breakdowns, repairs and replacements.[216] However, few have expanded these to manage EOL, out-of-warranty products. For recyclers, building infrastructure for the widespread collection of e-waste is essential to enable better management of e-waste in the off-grid solar sector.

Cumulatively, the eight projects collected 251,629kg of solar-e-waste. At the organizational level, this ranged from 75kg to 86,000kg. The projects articulate a number of operational considerations for off-grid solar (OGS) companies and recyclers to consider when planning take-back and collection schemes, including geographical mapping to inform collection point locations, reverse logistics planning, staff training and utilization of existing informal collection networks.

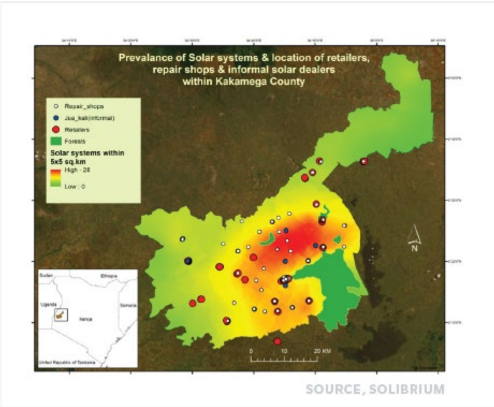
Understanding the local e-waste ecosystem and forecasting waste

The operational design and logistics of any take-back and collection scheme is highly dependent on the local e-waste ecosystem. The awardees deployed three methods to model the e-waste ecosystem. These included mapping the prevalence of off-grid solar products, forecasting the burden of e-waste over time, and surveying local actors of the informal e-waste value chain.

[215] E-waste Toolkit Module 5 and 6: Customer, Take-back and Collection, Rebecca Rhodes and Drew Corbyn, 2020

[216] See A Comprehensive Assessment of End-of-life SHS in Kenya; Challenges and Opportunities, Maria Vincente Garcia, 2018, (Vincente, 2019) and The afterlives of solar power: Waste and repair off the grid in Kenya, Jamie Cross and Declan Murray, 2018 (Cross & Murray, 2018)

Figure 4. Prevalence of OGS consumers, dealers and repair shops in Kakamega County, Kenya (Source: Solibrium Solar)



"Within five years it is expected that solar e-waste [in Kakamega County, Kenya] will exceed 50 tonnes annually and at various levels of market growth the waste is projected to accumulate at 165 to 230 tonnes per year by 2029, assuming current repair infrastructure and use behaviours."

–Solibrium Halfway Report, Kakamega County, Kenya

Off-grid solar companies can fill the e-waste information gaps by ensuring that basic customer data is collected during every sale (for example, each customer's village/district), and using service offerings like extended warranties to foster long-term customer engagement. It is recommended that companies use sales volumes and expected product lifespan to forecast e-waste volumes, hence enabling appropriate capacity to be built into take-back and collection schemes. Finally, surveying informal actors within the e-waste value chain helped the companies to identify where the ecosystem was most active, and thus locate collection points to leverage the existing network of informal e-waste collectors.

Implementing an effective take-back and collection scheme

Across the eight awardees, a total of 415 collection points for solar e-waste were established. The set-up cost per collection point ranged from US $20 for a simple "bin" at an existing location to US $2,550 for larger-scale infrastructure such as a converted shipping container in a new location. Companies whose main focus is distribution mostly used their existing networks of service centres or points of sale (e.g., shops and kiosks). Others set up special locations for e-waste collection.

The following considerations are useful when establishing collection points as part of a take-back scheme:

1. Who is the target user of the take-back scheme or collection point?

   Most take-back schemes target consumers. However, one company found that by working directly with informal scrap dealers rather than with consumers, they were able to increase their collection rates and reduce the cost of collected e-waste (paying US $0.28-0.42 per kg to local scrap dealers instead of up to US $3 kg if direct from consumers).

2. Where should the collection points be located?

   Consumers who returned solar e-waste travelled between 9km and 19km to reach the collection point – many by foot, bicycle or public bus. Where the distance is greater, customers will likely need a bigger incentive to return the waste, which adds to the overall cost of a long-term take-back scheme. On the other hand, collection points with larger capacity will also require easy access to main roads and transport hubs.

3. What products should be accepted?

   The projects found that the parameters of accepted items should be considered prior to implementation and seek to balance cost with impact. One company initially found that consumers were prone to return EOL products without the battery included – and for products with a separate PV panel, this was missing in more than half of returns. This is problematic due to environmental concerns of improper battery or panel disposal. Thus, the company encouraged consumers to return only intact solar products, which at first reduced returns. However, after adapting consumer messaging, collection volumes increased again.

The key lessons for take-back and collection from the Solar E-Waste Challenge pilot projects are summarized below:

- **Collection points should leverage existing infrastructure for maximum impact at low cost**. To serve low-income, last-mile customers, OGS companies often have extensive distribution networks that can be utilised in any take-back scheme. Collection points can easily set up in shops or service centres. For those willing to invest time to establish effective relationships, using local repair shops and community centres such as schools can also increase the volume of waste collected. However, recyclers targeting much bigger quantities of solar e-waste (along with other household electronics) benefit from building dedicated collection points in targeted locations.
- **Where possible, take-back schemes should be brand agnostic to recover as much OGS e-waste as possible from consumers.** Although this increases disposal and treatment costs for companies, it can strengthen the brand's reputation and attract new customers through incentives to purchase new, quality-verified products. In a sample of 120 products collected by one company in Kenya, 15 different brands were represented.

Recycling

At present, volumes of off-grid solar e-waste are still low, so the demand for recycling services is insufficient to drive economies of scale. The Solar E-Waste Challenge found that the treatment of off-grid solar e-waste costs about US $ 0.75 per kg.[217] Increasing volumes of collected waste can help drive down this cost. However, collected e-waste is often stored indefinitely (which has cost and risk implications), dumped in landfills, or informally dismantled and burned.

The key lessons in recycling from the Solar E-Waste Challenge pilots are summarized below:

- **Develop and implement supportive legislative and policy framework**. Policies can create subsidies for recyclers, reduce illegal movement of e-waste and harness existing recycling infrastructure in different countries.
- Increase investment for robust collection and treatment infrastructure and new business models to ensure sufficient volumes and eventual profitability.

Advancing e-waste management in off-grid solar

Gender inclusion

The awardees explored the demographics of solar e-waste management, particularly the gender division. Over the project period, 20% of people hired and 30% of people trained to implement the project activities were women. Among users, however, no discernible trends were detected in terms of gender or age; men and women visited collection points in roughly equal numbers, and their ages ranged from late teens to over- 50s.

The informal sector – that worked as partners to the projects rather than employees – demonstrated more distinct patterns. In one project, women served as sales agents, but the third-party collectors they worked with were overwhelmingly male. Waste collection and repair work across the projects was overwhelmingly "seen as a job meant for men."[218]

These observations suggest that awareness raising targeting end users should remain universal, while efforts could be made to further engage women throughout the EOL value chain. It is important to include gender disaggregated data to monitor and improve the inclusivity of EoL solar e-waste management.

Balancing the cost of solar e-waste

The cost of e-waste management remains a significant barrier to OGS companies. Many companies lack the resources to build operations to manage EoL products, while simultaneously focusing on the profitability of their core business and maintaining product affordability for low-income consumers.

[217] Efficiency For Access. Innovations in Lessons in Solar E-Waste Management, March 2021
[218] Qualitative insights from primary research, obtained via surveying employees and agents from the Projects.

For cost analysis, the e-waste chain is broken into four stages: access to waste, collection, transport and treatment.[219] The following estimates build on cost analyses originally carried out by DFID (FCDO) in July 2016,[220] and by GOGLA in 2019.[221] CLASP used data gleaned from the awardees to refine the cost of access, transport and treatment of e-waste. The original assumption regarding the cost of collection was retained because operating expense data for the management of collection points was unavailable within the Challenge timescale.

From the awardees, we estimate[222] that an entry level solar lantern (PSP1) has a negative value (therefore, a cost) of US $ -1.36/unit at EoL, a solar lantern with external PV panel (PSP2) has a negative value of US$-2.17/unit, while an SHS with a lead acid battery has a positive value of US$1.01/unit. From the original estimates made by DFID, these values have decreased from US$-0.85, US$-1.35 and US$2.2, respectively.

Conclusion

The first round of the Global LEAP Solar E-Waste Challenge successfully piloted several innovations to address barriers to effective solar e-waste management in the off-grid sector. The projects increased the volume of OGS e-waste collected in Sub-Saharan Africa by over 251 tonnes; reached approximately six million people through consumer awareness campaigns; tested take-back and incentive models; and increased the capacity for OGS recycling on the continent to 30,000 tonnes per year though Enviroserve, Hinckley and WEEE Centre.

The cost of accessing and treating off-grid solar e-waste remains high. Long-term sustainability of the projects would require further financial support, especially to ensure affordability for customers. But through the Challenge, the sector is better equipped to raise consumer awareness, pilot end-user incentives, and understand the viability of third-party repair partnerships. Crucially, the Challenge showed that all such interventions cost time and money. The sector, governments, investors and donors should contribute the funding necessary to de-risk, scale up and replicate these pioneering projects.

Following the Challenge, solar e-waste stakeholders can take the following actions:

- Companies can leverage existing consumer touchpoints as a “quick-win” way to raise awareness of proper management of OGS products once they reach EOL.
- Industry-wide collaboration can catalyze efforts to increase access to waste (through joint collection schemes and consumer awareness campaigns), and support reliable repair for out-of-warranty products by enabling access to good quality spare parts and basic technical guidance for partners.
- Funders and investors can explore novel ways (such as RBF) to support early adopters, as well as innovative models to implement e-waste management to avoid passing on the cost to consumers.
- Governments can support the sector’s efforts by supporting lower import costs for OGS spare parts and components, and by developing regulation that supports responsible recycling.

Areas for future research:

- How can digital technology (such as blockchain or Pay-as-you-go software) help OGS companies track and manage solar e-waste?
- What can be done to combat e-waste from the ‘grey-market,’ which includes counterfeit and non-quality verified products imported into the market in high volumes?
- Does capacitating and funding recyclers yield better results in terms of (kg) e-waste collected and processed than OGS companies?

[219] See GOGLA E-Waste Toolkit, the Financials of E-Waste Management and Cost Benefit Analysis and Capacity Assessment for the Management of Electronic Waste (E-waste) in the Off-Grid Renewable Energy Sector in Kenya. July 2017, produced by Evidence on Demand with assistance of the UK Department for International Development (DFID).

[220] F Magalini, D Sinha Khetriwal and C Mugabo, Sustainable Management of E-Waste in the Off-Grid Renewable Energy Sector in Rwanda: Evidence on Demand, Department for International Development (2016).

[221] GOGLA, E-Waste Toolkit Module 3 Briefing Note, the Financials of E-waste Management (September 2019)

[222] The calculation uses the same methodology as in GOGLA E-waste Toolkit, the Financials of E-Waste Management with the following updated figures: cost of access (US$1.17/unit), cost of collection (no change), cost of transport (US$0.66/km), cost of treatment (US$0.73/kg, except for SHS where original data is used to account for the value of lead acid batteries). Original data was converted from Euros to US$ for comparison.

- Can a viable market for refurbished products be established and would it be sustainable for both companies and/or local repair technicians? What is the residual value of repaired and refurbished products?
- What is the best model for collaboration between the industry and the informal sector for sustainable e-waste management, and how can this be achieved?

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[15] Efficiency For Access. *Innovations in Lessons in Solar E-Waste Management* (March 2021)

[16] GOGLA. *The Financials of E-Waste Management and Cost Benefit Analysis and Capacity Assessment for the Management of Electronic Waste (E-waste) in the Off-Grid Renewable Energy Sector in Kenya* (July 2017).

[17] Magalini F., Sinha Khetriwal D., and Mugabo C. *Sustainable Management of E-Waste in the Off-Grid Renewable Energy Sector in Rwanda,* 2016.

[18] GOGLA. *E-Waste Toolkit Module 3 Briefing Note, the Financials of E-waste Management* (September 2019).

Can digital advertising raise consumer awareness of energy efficient domestic appliances? A case study of the #KenyaEnergyLabel campaign

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Abstract

In an effort to promote high-quality, efficient domestic appliances to reduce consumers' electricity costs, the Kenyan government developed and implemented a Kenya-specific energy labeling scheme. Labeling is a critical component of effective appliance energy policy, encouraging consumers to make informed purchase choices and protecting them from poor quality, inefficient products. However, consumer awareness, understanding, and trust in an energy label are central to its success. In 2019, the Energy and Petroleum Regulatory Authority (EPRA) requested support from CLASP to design and run an energy label consumer awareness campaign.

CLASP designed and implemented the digital #KenyaEnergyLabel campaign focused on the refrigerator, freezer, air conditioner, and motor labels across Facebook, Twitter, Instagram, and Google Ads for 4 months [October 2020 – February 2021]. The central campaign message, *More Stars, More Savings*, spoke to the five-star guide that demonstrates how much energy, and correlated energy expenditures, can be saved by purchasing appliances with higher star ratings. The campaign reached more than 2,500,000 Kenyans through 80 paid ads. This paper will share insights into the digital implementation of the campaign, evaluating consumer interactions with the advertisements and social media pages. The #KenyaEnergyLabel offers a case study for governments, regulatory entities, and other energy label stakeholders, outlining a low-cost, awareness raising intervention to target consumers and encourage the uptake of energy-efficient appliances.

Introduction

With a growing global population, increasing energy demands have resulted in overburdened energy systems, dependency on fossil fuels, and quickly diminishing natural resources. To combat negative environmental impacts and establish more sustainable, reliable, and cost-effective systems, there is a need for improvements in energy generation and more efficient utilization of existing energy.[223]

As the economies in sub-Saharan Africa grow, greater pressure is put on the energy services to supply consumers' household appliances, such as refrigerators, air conditioners, cookers, electric cars, air conditioners, and more.[224] Poor quality, low efficiency appliances strain national electricity supply systems and are more expensive to run.[225] Developing and implementing standards to raise the efficiency levels of household appliances can free up energy, reduce carbon emissions and contribute to national economic and social development. Minimum energy performance standards (MEPS) are used to transform markets toward energy efficient lighting and appliances, ensuring products meet certain specified criteria related to energy performance, quality of service, and longevity.[226] The United for Efficiency estimates the introduction of MEPS for lighting, refrigerators, air conditioners, transformers, and electric motors in Kenya could lead to

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[223] Avila, N., Carvallo, J. P., Shaw, B., & Kammen, D. M. (2017). The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers. *Generating Energy for Sustainable and Equitable Development, Part, 1*, 1-79.

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[226]Sonnenschein, J., Van Buskirk, R., Richter, J.L. et al. Minimum energy performance standards for the 1.5 °C target: an effective complement to carbon pricing. Energy Efficiency 12, 387–402 (2019). https://doi.org/10.1007/s12053-018-9669-x

approximately 0.88 TWh of energy savings, avoided CO2 emissions of 0.71 million tonnes, and 0.1 billion US dollars of energy bill savings by 2030. [227]

In addition to MEPS, appliance energy labeling programmes are used as an incentive to manufacturers and retailers to sell more efficient models of appliances with minimal environmental impacts over their lifetime.[228] Energy labels include information on product energy usage and performance, allowing consumers to make educated purchasing decisions. Energy labeling is a critical component of an effective appliance energy efficiency policy. While minimum energy performance standards (MEPS) remove the least-efficient products from the market, energy labels drive product markets to higher efficiency by:

- Allowing consumers to make informed purchasing decisions by differentiating high efficiency products from average and low efficiency products;
- Incentivizing the production of more efficient products by helping manufacturers market their high efficiency products, as labels provide unbiased evidence that products are more efficient; and
- Providing the foundation for market transformation programmes by allowing policymakers to easily identify high efficiency products to target for bulk purchasing, financing, and incentives.

Many leading global economies in the European Union, North America, and Australia have well established energy labeling programmes to reduce energy consumption and improve product quality. Over the past decade emerging economies, such as India and South Africa[229] have begun their own programmes. Recently Kenya and Ghana began the first energy labeling programmes in East and West Africa respectively.

In 2016, Kenya gazetted the Appliances' Energy Performance and Labelling Regulations targeting energy performance standards for refrigerators, freezers, non-ducted air conditioners, and electric motors. Kenya's Energy and Petroleum Regulatory Authority (EPRA) operates as the standards implementing agency. In 2019, the first national energy label, for domestic refrigerators, freezers, air conditioners and electric motors, became mandatory for all products sold on the Kenyan market. However, both consumers and retailers had limited knowledge and understanding of the purpose and utility of the energy label.

EPRA requested support from CLASP to design and run an energy label consumer awareness campaign focused on the four product categories covered by energy performance standards. The campaign also aimed to establish brand recognition around Kenyan energy efficiency labels for subsequent campaigns on other products covered by energy performance standards. The digital campaign was implemented between October 2019 and February 2021 on Google Ads and paid advertising on Facebook, Twitter, and Instagram. Prior to developing materials (in August 2019) and at the conclusion of the campaign (February 2021), CLASP conducted baseline and endline surveys to evaluate the changes in consumer perspectives, behavior, and label awareness.

This report aims to offer an in-depth analysis of the Kenya Energy Label campaign and examine the three platforms where the digital advertisements were implemented: Google, Facebook/Instagram, and Twitter. With a $3,700.00 budget, CLASP was able to target and reach 2,500,000 Kenyan consumers.

Kenya Appliance Market Overview

With a population of 50 million people, Kenya's economic growth from 2015-19 averaged 5.7%,[230] making it one of the fastest growing economies in Sub-Saharan Africa. The stable government, growing middle-class,

[227] United for Efficiency,2018. Country Assessment:Kenya Savings Policy Assessment. https://united4efficiency.org/country-assessments/kenya/

[228] Mahlia, T. M. I., Haji Hassan Masjuki, Rahman Saidur, and M. A. Amalina. "Cost-benefit analysis of implementing minimum energy efficiency standards for household refrigerator-freezers in Malaysia." Energy policy 32, no. 16 (2004): 1819-1824.

[229] Turiel, Isaac. "Present status of residential appliance energy efficiency standards—an international review." Energy and buildings 26, no. 1 (1997): 5-15.

[230] World Bank. "Overview of Kenya" https://www.worldbank.org/en/country/kenya/overview#1

and increase of women in the workforce have resulted in increased demand for household appliances like refrigerators and washing machines; in 2018, Kenya registered sales of around 403.16 thousand units of household appliances.[231] Rapid urbanization is expected to substantially increase the home appliance market in the coming years.

The first few appliances purchased by grid-connected Kenyan households are lights, televisions, cooling appliances (refrigerators, freezers), and small kitchen appliances such as blenders, water heaters, and juicers. Other commonly purchased appliances include cookers, ovens, and microwaves. [232]

Data Collection and Methodology

Prior to developing materials for the #KenyaEnergyLabel campaign, CLASP contracted a survey team to conduct a baseline survey (in August 2019) to better understand the factors that influence consumer decision making when purchasing appliances and existing awareness of the Kenya energy label. Data from the baseline survey was used to design appropriate messaging and branding for the campaign. The baseline survey was conducted for one week in-person in Nairobi, Mombasa, Kisumu, and Eldoret in large retail outlets like Naivas, Tuskys, Hotpoint, and Carrefour. The questionnaire focused only on the refrigerator label,[233] but assumptions could be made about consumer awareness and understanding of appliance energy labels in general.

CLASP contracted a Nairobi-based marketing firm EXP Agency Kenya (Exp) to develop the graphics and messaging materials for the campaign. Using insights from the baseline survey on consumer purchasing decisions, EXP Marketing developed a variety of messaging and imagery to promote the label on online platforms. EXP Marketing pre-tested the communication materials through focus group discussions with Kenyans of different ages and genders. CLASP then scheduled social media posts to go out 20-25 days per month on Twitter and Facebook, and once a week on Instagram. Google ads ran daily for 4-months (October-January). CLASP collected data throughout Google, Facebook/Instagram, and Twitter on the demographics of consumers interacting with the ads.

Campaign Design

Baseline Survey

Understanding demographics, factors influencing consumer decision making, and awareness of the energy label is fundamental to designing appropriate messaging and evaluating campaign success. CLASP conducted a baseline survey to provide technical evidence to design the #KenyaEnergyLabel campaign. The baseline survey was conducted in August 2019, eight months after the first Kenya Energy Label (for refrigerators) entered the market. The survey focused only on the refrigerator label, but assumptions can be made about consumer awareness and understanding of appliance energy labels in general.
The baseline survey included nine hundred and four (904) appliance customers in four cities—Nairobi (and surrounding peri-urban areas), Mombasa, Kisumu, and Eldoret in large retail outlets like Naivas, Tuskys, Hotpoint, and Carrefour. Of the respondents, four hundred and fifty-one (451) were male and four hundred and fifty-three (453) were female. More than half of the interviews were conducted in Nairobi (51%) followed by Mombasa (21.7%). The least number of respondents were from other small towns (2%). The highest number of respondents were in the age group 24-35, with 51.5% females and 48.5% males.

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[231] Research and Markets. "Kenyan home appliances market review 2014-2019 and forecast to 2027: A $363+opportunity." https://www.globenewswire.com/news-release/2019/08/30/1908972/0/en/Kenyan-Home-Appliances-Market-Review-2014-2019-and-Forecast-to-2027-A-363M-Opportunity.html

[232] Research and Markets, Global Newswire,2019. The Kenya Home appliance Market Outlook and Industry Analyis opportunity Evaluation 2014-2027.

[233] The baseline survey focused only on refrigerators because at the time (August 2019) this was the only label on the market. CLASP made assumptions about consumer perspectives on additional products under the the labeling scheme based on feedback on the refrigerator energy label.

The main findings from the baseline survey are summarized below:

1. **Refrigerator customers care about the price of products, above all other considerations.** When asked what factors they consider most important when purchasing a refrigerator (price, brand, energy consumption, components, and size), 60% of respondents ranked price as the most important. This sentiment was affirmed through other questions, with consumers emphasizing they look for a product that balances price with performance.
2. **While refrigerator users claim to care about their products' energy consumption, few track energy consumption.** The survey was designed to gauge consumers' attitudes towards energy conservation—81% of respondents said they cared about how much electricity their product consumed, but only 27% knew how much energy their products consumed.
3. **The majority of customers conduct research prior to purchasing refrigerators.** Over two-thirds of respondents cited conducting research prior to purchasing a product, primarily seeking recommendations from family or friends, searching online, or speaking with retailers in distribution outlets. This data indicates that consumers care about the quality and performance of products and dedicate time to identify the best option to meet their unique needs.
4. **Most consumers do not recognize or know how to use the Kenya Energy Label but indicated that with more knowledge they would use the label to help in their purchasing decisions.** All respondents were shown the label, 66% did not recognize the label and 85% of respondents did not know what the label meant. However, 82% of respondents who did not recognize the label reported that if they better understood the label, it would influence their purchase choice.

After analyzing the data from the baseline survey, the recommendations below summarize the key take-aways for campaign design.

Recommendation 1: Incorporate messaging about cost-savings into the consumer awareness campaign. Consumers care about the upfront cost of their refrigerators, indicating they want to buy cost-effective products. Designing campaign messaging around the long-term cost savings of higher-efficiency products will encourage customers to purchase products with higher star ratings, despite higher upfront costs.

Recommendation 2: Incorporate messaging about energy-savings into consumer awareness campaign. Consumers claim to care about product energy consumption and will therefore seek higher-efficiency products. The consumer awareness campaign should include messaging around energy consumption, monthly electricity tokens, and energy savings to appeal to energy-conscious consumers.

Recommendation 3: Advertise the consumer awareness campaign on the platforms consumers use to research products. Consumers primarily conduct research online and through retailers at the point of purchase. Running online ads through Google and social media will reach customers who search online for further information. The campaign should also incorporate messaging around spreading the information to your friends and family, as the majority of pre-purchase research comes from recommendations.

Material Development

CLASP contracted a Nairobi-based marketing firm EXP Agency Kenya (Exp) to develop the graphics and messaging materials for the campaign. While EPRA has been promoting the energy label, it was important to create a brand independent of EPRA focused solely on the energy label so that messaging would not get lost in other EPRA-related posts and news.

Figure 1. The Kenya Energy Label for air conditioners

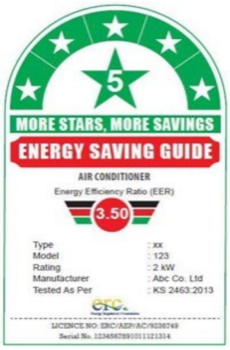


Figure 2. The Kenya Energy Label logo

Using the label **Figure 1** as inspiration, the design firm created a logo **Figure 2** and brand guidelines for the Kenya Energy Label. The colors of the label reflect the Kenya national flag, so the label brand was very Kenya-forward to differentiate it from other energy labels present on the Kenyan market that may confuse the consumer (notably from the European Union).

Taking insights from the baseline survey on consumer purchasing decisions, EXP developed a variety of messaging and imagery to promote the label on online platforms. To achieve relevant messaging that would resonate with consumers, EXP Marketing pre-tested the communication materials, as explained below. The pre-test exercise was aimed at understanding the audience take-out with respect to the following key areas:

1. Could the target audience **identify with the campaign messages**?
2. Were the campaign messages **clear** to our target audience?
3. Was the **artwork relevant** to the target audience and could they easily interpret them?
4. Does the target audience **recognize the benefits** being offered?
5. Do they believe the **promise** being made?
6. What are their **general interest levels** and feelings about the campaign message?
7. Was the message **persuasive** to them?

EXP Marketing conducted 3 interactive digital Focus Group Discussions with men, women, and youth consisting of 8-11 respondents. Each group was taken through the campaign materials and messaging in a bid to get their feedback. The pre-test methodology used was the cognitive interviewing method, where the facilitator used open ended questions to get feedback from the participants.

The focus group was shown a variety of images and messaging – they generally liked green graphics because that depicted money for cost-savings and environmentally friendly appliance. They said that messaging should be specific that more stars means more *energy* or *cost* savings.

Campaign Implementation

Once the campaign materials were finalized, CLASP set up social media pages, Google advertisements and a webpage hosted by EPRA that gave more details on the energy label programme and usage. With a budget of $3,700.00, the team tested out a variety of ad types with the goal to reach as many consumers across Kenya as possible.

Figure 25. Label

Figure 4. Appliance-specific

Figure 24. Multi-appliance

The campaign was divided into three themes, implemented during a roughly 4-month period:

- **October 2020**: Campaign kick-off. Messaging focused on an introduction to the Kenya Energy Label using graphics like **Figure 3**.
- **November-December 2020**: Appliance specific messaging. Messaging focused on the three appliance categories under the energy label scheme (refrigerators/freezers, air conditioners, electric motors). Also capitalized on the holiday season to include messaging on cost-saving holiday purchases. Primarily used graphics like **Figure 4**.
- **January-February 2021**: General label & appliance messaging. To wrap up the campaign, the final months focused on general messaging with graphics including all the appliances under the label scheme **Figure 5**.

CLASP considered a successful social media ad one that had a high conversion rate, meaning consumers not only saw the ad in their feed or their search engine, but also took an action (e.g., clicked the ad that took them to the EPRA website[234], liked a page or post, or sent a direct message to the social media pages). A high social media conversion rate, in general, was 10-15% (e.g., 10-15% of consumers took an action after seeing it).

Other metrics to evaluate the success of a digital campaign like the #KenyaEnergyLabel are tracking website and social media page traffic to see if more users are visiting the pages. Certain website servers can also track the length of time a visitor stayed on the webpage. We focused on the conversion rate because it indicated whether viewers of the ad took an action to learn more about the campaign.

Campaign Implementation

Google

CLASP ran Google ads daily for 4-months (October-January). Google ad conversion rates tend to be much lower than social media platforms – generally because the ads are shown to more people. An expected conversion rate is 1-7%. The average conversion rate on Google ads is 3.75%, with the highest 25% of companies reaching 11.45%. Due to the limited budget of the campaign, CLASP could not afford to run the types of ads that garnered higher conversion rates (such as ads with graphics).

[234] https://www.epra.go.ke/services/energy-efficiency-project/user-manuals/

Table 12. Overview of #KenyaEnergyLabel Google ads

Website Link	EPRA User Manuals
Ads	3
Duration	4 months
Impressions	1,280,000
Engagements	13,100
Conversion	1.02%
Cost (USD)	$1,370.00

Over the campaign implementation period, CLASP tested 3 unique ads on Google to reach 1.28 million consumers and elicited more than 13,000 clicks, spending a total $1,370.00 USD. The ads (**Figure 6- 8**) linked to the EPRA User Manual webpage which provided more in-depth information on the label.

Figure 27. Google Ad 1

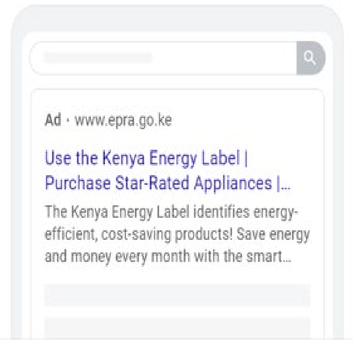


Figure 26. Google Ad 2

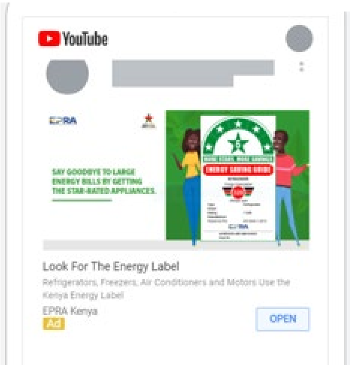
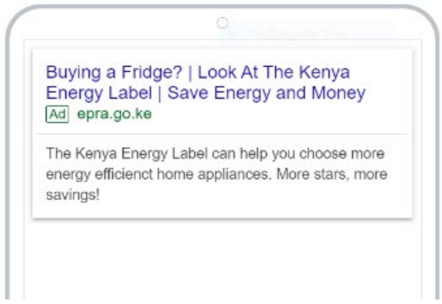


Figure 28. Google Ad 3



Google Ad 1

The first ad piloted (**Figure 6**) did not include imagery and encouraged consumers to purchase appliances with the Kenya Energy Label. This ad initially ran in October to introduce the energy label, but because of its success in comparison to the other ads, CLASP continued to run it for the duration of the campaign. The ad aimed to get consumers to click on the link that brought them to the EPRA User Manuals. This was the most cost-effective and successful ad—in terms of reach to engagement ratio. Overall, this ad reached 1,202,014 consumers and garnered 12,500 clicks for a total cost of $1,045.15 USD. The ad averaged $7.00 USD per day.

The impression-to-conversion rate for this ad was 1.03%. While this conversion rate does not appear as high as Google averages (3.75%), it was the highest and most cost-effective for all piloted Google ads. The main locations it reached were Nairobi, Ruiru, and Mombasa (998,000) with the most impressions among the age group 25-34 (417,000).

To reach consumers, the ad appeared in Google searches for the following keywords: *energy efficiency, easy ways to save money, save energy, energy, electric energy, air conditioners, refrigerators, and KPLC.*[5]

Google Ad 2

The second ad piloted (**Figure 7**) included a carrousel of imagery, highlighting the appliances under the energy label scheme. This ad cost $36.00 USD per day to run, significantly more expensive because it featured a collection of images and messaging. The ad reached 72,210 consumers, but only converted 369 into clicks. The conversion rate was therefore only 0.51%. We discontinued the ad after only two weeks due to its unsuccessful performance.

Google Ad 3

The third ad (**Figure 8**) performed best in terms of conversions with an average cost of $15.00 per day. The ad reached 8,851 consumers and garnered 233 clicks—the conversion rate was therefore 2.63%. The ad, however, focused only on refrigerators so was not applicable to the aim of the campaign which was to sensitize consumers to all products under the label scheme.

Keywords that worked well for this ad included: *lower energy bill, saving energy, reduce electric bill, and home energy savings*.

Recommendations:

- Test a variety of messaging and graphics to identify which ads have the highest conversion rate.
- Include keywords related to energy and cost-savings to target consumers who are conscious of their energy savings.
- Google is a strong tool to encourage consumers to click on a website, however, does not retain long-term consumers for ongoing messaging like social media pages.

Facebook and Instagram Content & Ads

Table 13. Overview of #KenyaEnergyLabel Facebook/Instagram ads

Platforms	Kenya Energy Label @kenya_energy_label
Ads	56
Duration	4 months
Impressions	1,052,950
Engagements	393,728
Conversion	37.4%
Cost (USD)	$1,384.69

Facebook and Instagram were the most successful and far-reaching social media platforms for both ads and regular posts. Because Instagram was acquired by Facebook, CLASP ran the same media across both platforms simultaneously. While CLASP did run and post Instagram-specific content, the majority of reach was conducted through the Facebook ad platform. Over the 4-month implementation period, CLASP ran 56 unique ads to reach 1,052,950 consumers, spending $1,384.69 USD. As of April 2021,[235] the Kenya Energy Label Facebook had 5,800 followers and the Instagram had 343 followers.

- Instagram-specific: through Instagram, we engaged 147,072 consumers spending $510.62 USD.
- Facebook-specific: through Facebook, we engaged 256,832 consumers spending $871.91 USD.

Across both platforms, the campaign was most successful in the 25-34 age group (34% of men and 22% of women fell into this category). The messaging also reached significantly more men (59%) than women (41%). Notably, Facebook ads resonated better with men (65%), whereas Instagram demonstrated the opposite trend with roughly 65% of women engaging with ads on that platform.

The Facebook/Instagram campaigns tested a variety of ad types: Link Clicks, Post Engagement, Instagram Profile Visits, Page Likes, Conversations and Instagram/Facebook Story Promotions. The most successful ads in terms of conversions were Post Engagement ads, which generally boasted a conversion of 30-50% (post likes). However, Page/Profile visits were also very successful on the Facebook platform. Ads featuring the animated characters with messaging on cost savings were most successful. In terms of appliances, imagery with refrigerators and electric motors performed best.

Figures 9-11 are examples of successful Facebook and Instagram ads.

Figure 29. Post Engagement

Figure 31. Post Engagement Instagram Ad

Figure 30. Page Likes

Social media conversions are significantly higher than Google Ads because they do not require consumers to go to an external website and the engagement action is easier—e.g., liking or following a page. The majority of users viewed ads on mobile phones. In Kenya, telecom providers offer data bundles for social media. CLASP assumed that many users did not click on the EPRA website because their data bundle did not extend to general internet services. It is therefore important to provide all essential information on the label utility directly on social media pages.

Recommendations:

- Test a variety of messaging and graphics to identify which ads have the highest conversion rate.

[235] CLASP officially transferred management of the Kenya Energy Label pages over to EPRA in April 2021.

- Website click ads did not have very high conversion rates. Include messaging about the utility of the label directly on social media so users without internet search data bundles will receive all relevant information.
- Conduct social media advertising across a range of platforms because disparate age and gender demographics prefer different platforms (e.g. Facebook was more popular with men and Instagram was more popular with women).

Twitter

While not as successful as Facebook in terms of engagement, Twitter was a valuable tool to affordably reach consumers. Over the 4-month implementation period, CLASP conducted 21 ads for Page Likes, Engagements and Impressions. CLASP focused on Impressions—arguably Twitter's greatest strength—which meant the ads appeared in consumers' Twitter feeds. The cost per ad ranged from $40-100 USD and we usually ran them for 7-10 days. As of April 2021, @EnergyLabelKE has 699 followers.

Table 14. Overview of #KenyaEnergyLabel Twitter ads

Platforms	@EnergyLabelKE
Ads	21
Duration	4 months
Impressions	556,771
Conversion	37.4%
Cost (USD)	$973.97

The majority of Twitter engagements were with male users (79.2%) on Android devices (78.9%) in the age group 20-39 (74.7%). CLASP did not target any specific demographics beyond limiting the ad location to Kenya. Figures 12 and 13 represent some of the most successful Twitter ads.

Figure 33. Post Engagement Ad

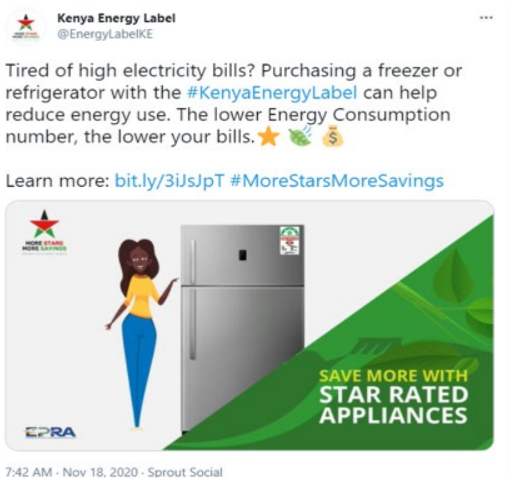
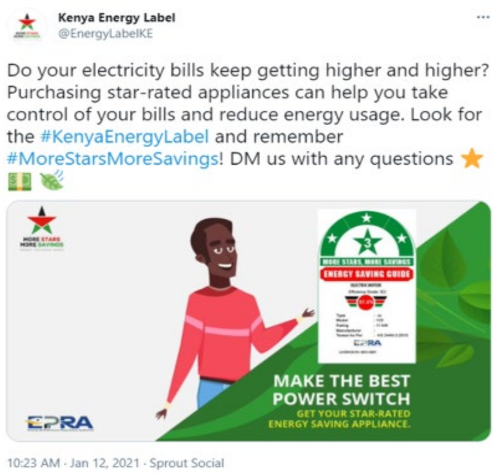


Figure 32. Post Engagement Ad



Twitter is one of the most popular social media platforms in Kenya, so the relatively low rate of success on the platform was surprising. The biggest jump in followers for @EnergyLabelKE was when the EPRA Twitter account (@EPRA_Ke) shared or tweeted about the label. EPRA boasts significantly more followers (58.8k) so leveraging more established pages to convey messaging is key to success.

Recommendations:

- Test a variety of messaging and graphics to identify which ads have the highest conversion rate.
- Tag and encourage partners with more followers to tweet and share the energy label page to ensure higher exposure.
- Tailor ads to specific consumer groups if it appears that they are only showing up for specific demographic categories, e.g., young males on Android devices.

Digital Advertisements for Energy Label Programme Learnings

Endline Survey

After the conclusion of the campaign, CLASP conducted an endline survey to evaluate consumer behavior change after interacting with the campaign, as well as reach and impact of Kenya Energy Label social media and digital ads. The endline survey was conducted online and through phone calls with 1230 respondents from Nairobi, Mombasa, Kisumu, Eldoret, Meru, Nanyuki and a few other small towns. Of the respondents, six hundred and forty-three (643) were male, five hundred and eighty-four (584) were female and three (3) were other genders.

The main findings are summarized below:

- **The number of respondents who cared how much energy their appliances consumed increased** from 81% in the baseline survey to 87.7% in the endline survey.
- **When purchasing an appliance, consumers showed an increase in consideration for appliance energy consumption**—48% of respondents ranked energy consumption as most important factor.
- **The majority of customers (68.46%) conduct research prior to purchasing appliances.** This is consistent with the baseline survey where 67% of respondents reported conducting research prior to purchasing an appliance.
- **There was a substantial increase in the number of respondents who have seen the Kenya Energy Label** from 34.1% in the baseline survey to 58.9% in the endline survey.
- **Of the respondents who had seen the Kenya Energy Label, 30.66% had seen the label online via social media or advertisements.**
- **More people understood the meaning of the Kenya Energy Label.** The percentage of respondents who knew what the label meant increased from 15% in the baseline survey to 28.05% in the endline survey.

Key Learnings

Through the #KenyaEnergyLabel programme, CLASP learned it is necessary to test a variety of messaging and graphics to identify which ads have the highest conversion rate. Conducting ads across different digital platforms allowed the campaign to reach disparate demographic groups. Further, by testing a variety of ad types, the campaign reached more than 2.5 million Kenyan consumers and garner long-term page followers.[236]

[236] The campaign accumulated more than 7,000 followers across all platforms by the end of implementation.

Digital advertising is cost-effective, reaches consumers in an increasingly social media-based world, and allows rapid data insights on ad performance so that campaign implementers can constantly adapt messaging. Traditional media (radio, television, billboards, etc.) are more expensive and more difficult to track in terms of success and demographic reach. When researching platforms for campaign implementation, CLASP considered traditional media options but the cost to run one television ad was roughly the same cost as the entire digital campaign.

The COVID-19 pandemic led to a national shutdown in the midst of the #KenyaEnergyLabel campaign. CLASP initially planned to conduct retailer awareness training and in-person awareness raising activities, but with the pandemic shifted the campaign to be fully digital. Because more people were at home and shopping online, pivoting to a fully digital approach met consumers where they were spending the most amount of time.

In addition to collecting extensive data on consumer interactions with the ads, CLASP and EPRA also interacted directly with consumers daily through direct messaging and post comments. The team responded to every question and comment made by customers across multiple platforms to dispel myths about the label and ensure messaging was not muddled through third-party communicators.[237] As global home appliance markets become increasingly digital, energy label programmes should adapt to meet the needs of consumers. Digital marketing is an inexpensive, targeted method that can be integrated into standards and labeling programmes around the world—adapted for the cultural and demographic nuances of each location.

Campaign Challenges

- **Budget constraints**. The #KenyaEnergylabel campaign was conducted within a low budget to accommodate realistic capacity at EPRA. In future campaigns, CLASP would increase the budget for material development, staff time allocation, and campaign roll-out (paying for ads).
- **Handover to EPRA**: After the initial 4-months of digital advertising, CLASP transferred campaign management to EPRA. Since transferring, the social media pages have been largely dormant. Thus, the reach and messaging have been reduced.
- **Language Limitations**: On all platforms, CLASP implemented the campaign in English (both the graphics and messaging). Even though English is Kenya's official language, Kiswahili is the national language and spoken by the majority of the population. The social media pages received comments and questions in other native languages, restricting the amount of information we could provide due to the CLASP staff's language barrier (speaking English and Kiswahili only). There are 68 languages spoken in Kenya so future campaigns should take into consideration tailored messaging for different regions and ethnic groups.
- **Time limitations**: CLASP initially planned to conduct the campaign for 12-months (December 2019-December 2020) but delays in material development, difficulties identifying relevant marketing partners and COVID-19 derailed this plan. If CLASP had conducted the campaign over a longer timeframe, it could have reached significantly more consumers and further refined and targeted messaging.
- **Staff Constraints**: While CLASP contracted a survey team and graphic designers to prepare the campaign, survey analysis and campaign implementation were all conducted in-house. The CLASP team lead on the project only had the capacity to dedicate 25% of their time to the project. Given time restraints, with a full-time staff person managing the campaign, it could have been more successful.
- **Partner outreach**: While we prepared extensive content for partners to share across their channels, most did not share the #KenyaEnergyLabel materials. Convening a meeting or press conference could have increased reach.
- **Press outreach**: CLASP and EPRA shared the materials with press contacts but had limited success with posts in big media outlets. In future campaigns, CLASP would increase press outreach at the onset of the campaign.

Conclusions

[237] Such as retailers trying to explain the label, without fully understanding it themselves.

The #KenyaEnergyLabel Campaign reached 2.5 million consumers across Kenya, increasing awareness and understanding of the label and appliance energy consumption in general. The case study in Kenya offers a low-cost option to increase recognition and awareness of a new or existing energy label scheme. Digital advertising provides an opportunity for government regulatory agencies or other energy label stakeholders to reach and interact with consumers directly; this method is particularly useful in providing accurate information in real time and dispelling concerns or misconceptions about the label.

As the world becomes increasingly digital, labeling programmes should adapt to meet this changing landscape. Using Google, Facebook, Instagram, and Twitter can target groups by age, gender, interests, and other demographic factors with relevant and context-specific messaging; ultimately driving them to select higher-performing appliances. The lessons from the #KenyaEnergyLabel can be replicated in most markets around the world where social media and Google play a prominent role in the daily lives of consumers.

In future campaigns, CLASP recommends 6 to 18 months for campaign implementation to allow more time for people and businesses to interact with the campaign materials. However, the case study in Kenya and lessons learned could be replicated in other nascent domestic appliance markets. Digital campaigns are an option no matter how time or cost-restricted a labeling programme maybe—with less than $4,000 USD for campaign roll-out, CLASP reached millions of individuals across Kenya.

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5 HEATING AND COOLING

Final impact assessment of the novel highly efficient and fuel flexible medium-scale HiEff-BioPower CHP technology using a solid oxide fuel cell (SOFC)

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Abstract

The EU Horizon 2020 project HiEff-BioPower (grant agreement No 727330, duration: 10/2016 – 09/2021) aimed at the development of a new, innovative, fuel flexible and highly efficient biomass CHP technology for a capacity range of 1 to 10 MW total energy output, suitable e.g. for on-site generation at larger residential apartment buildings or local heat grids. The new technology shall define a new milestone in terms of CHP efficiency and contribute to a sustainable energy supply based on renewable energies using otherwise unused residual biomass. It consists of a fuel-flexible updraft gasification technology with ultra-low particulate matter emissions, an integrated gas cleaning system and a solid oxide fuel cell (SOFC). The technology shall be applicable for a wide fuel spectrum for residual biomass (wood pellets, wood chips or selected agricultural fuels like agro-pellets) and achieve high gross electric (40%) and overall (90%) efficiencies as well as almost zero gaseous and particulate matter (PM) emissions (close or below the level of detection) as non-energy benefits. At the end of the project, final technology data has become available, as well as techno-economic analyses and market studies. Based on this data, this paper presents final results from the environmental impact assessment of the new HiEff-BioPower technology.

Introduction

As part of it's recent Fit-for-55 package, the European Commission's targets to achieve a share of at least 40% renewables in the Union's final energy consumption [1]. As the current solid biomass combustion in the EU is already significant and a further expansion is planned, it is important to consider a maximum of efficiency, reduction of emissions and the usage of sustainable biomass especially from residues that would be otherwise not be used at all. As result of complex feedstock composition and heat integration, most combined heat and power (CHP) systems based on biomass fuels are still realised only for medium and large-scale plants with typically 0.2 MW_{el} up to more than 100 MW_{el}. Although mature technologies like steam turbine cycles or Organic Rankine Cycle (ORC) processes exist, major drawbacks of the current systems are their restricted fuel flexibility especially regarding the utilisation of forestry or agricultural residual biomass as well as their limited electric efficiencies of typically 14 to 27% [2]. Considering this background, the H2020 project HiEff-BioPower aimed at the development of a new, innovative, fuel flexible and highly efficient medium-scale biomass CHP technology for a capacity range of 1 to 10 MW total energy output. It consists of (i) a fuel-flexible fixed-bed updraft gasifier, (ii) a novel gas cleaning system and (iii) a solid oxide fuel cell (SOFC). The technology shall be applicable for a wide fuel spectrum of biomass residues like wood pellets, wood chips, short rotation coppice (SRC), selected agricultural fuels like agro-pellets or fruit stones/shells and shall achieve at the same time high gross electric and overall efficiencies as well as almost zero gaseous and particulate matter (PM) emissions (close or below the level of detection).

Therefore, in advance of any large-scale future deployment of new technologies, the potential environmental impacts have to be adequately assessed. Accordingly, the overall project methodology was divided into a technology development part (process simulations, computer aided design of the single units and the overall system, test plant construction, performance and evaluation of test runs, risk and safety analyses) and a related comprehensive technology assessment part covering techno-economic, environmental and overall impact assessments as well as market studies regarding the potentials for application. This paper presents final results of the HiEff-BioPower overall impact assessment. More information on the technical details and backgrounds of the project is presented under https://www.hieff-biopower.eu/.

Objectives

The objectives of the overall impact assessment (IA) are to estimate the expected effects of a broad market introduction of the new, fuel flexible HiEff-BioPower CHP technology in the EU. Accordingly, this paper will have a major focus on European greenhouse gas (GHG) and air pollutant emissions, as well as fuel and energy consumption. With the background of ambitious EU climate protection targets, biomass solid fuel heating is often intended to be scaled up for taking a major role in future low-carbon energy heating and power generation strategies. E.g. the Green-X EUCO27 scenario developed on behalf of the European Commission expects biomass heat production to grow from 80 Mtoe in 2014 to 104 Mtoe in 2030 and biomass energy demand for electricity generation is expected to increase from 14 Mtoe in 2014 to 24 Mtoe in 2030 [3]. In this context, the analysis how the new HiEff-BioPower technology compares to competing technologies is one major objective of this impact assessment. In parallel to the reduction of GHG emissions, the EU also aims to further improve air quality throughout Europe. In 2016, the amended Directive on the reduction of national emissions of certain atmospheric pollutants (2016/2284/EU) has been passed. With this legislation the European Union laid the foundation to take further steps towards the long-term target of achieving a level of air quality that does not have significant negative impacts on and risks to human health and the environment. In this context, solid fuel combustion in old and outdated heating systems has been identified as one of the main sources for particulate matter (PM) related ambient air pollution in the EU. While particulate matter is often distinguished by different sizes of particles, for the purposes of this impact assessment the aggregated indicator of total suspended particle (TSP) is used. Other important air quality-relevant pollutants are carbon monoxide (CO), organic gaseous compounds (OGC) and nitrogen oxides (NO_X). Therefore, estimating the effects of the new HiEff-BioPower CHP technology on TSP, CO, OGC and NO_X emissions compared to competing state-of-the-art technologies is another major objective of this impact assessment.

Methodology

The approach used for this impact assessment is derived from the Impact Assessment Guidelines of the European Commission [4], [5]. Four application cases have been identified for the analysis:

- Application A1 covers “small” CHP systems (200 kW_{el} / 260 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-up and shutdown cycles per year.

- Application A2 covers “small” CHP systems (200 kW_{el} / 260 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-up and shutdown cycles per year.

- Application B1 covers “large” CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-up and shutdown cycles per year.

- Application B2 covers “large” CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-up and shutdown cycles per year.

For each application case different technologies and fuels could be utilised. Therefore, the HiEff-BioPower technology is compared to other systems, which represent most likely alternatives to the new technology for customers or investors. The abbreviated names for each technology are given in parenthesis and these abbreviations are used throughout this paper in graphs and tables:

- Wood chip biomass boiler + electricity from the grid (BB_WC)

- Wood pellet gas engine (GE_WP)

- Wood chip HiEff-BioPower CHP (HEBP_WC)

- Miscanthus pellet HiEff-BioPower CHP (HEBP_MP)

The BB_WC and the GE_WP scenarios assume the use of existing state-of-the-art technologies, while the HEBP_WC and HEBP_MP scenarios suppose the use of the new HiEff-Biopower CHP system, albeit with different fuels (wood chips in the case of HEBP_WC, miscanthus pellets in the case of HEBP_MP).

All scenarios for the different application cases use the same assumptions for the stock of appliances. For each year t the stock is calculated from the formula

$$stock_{i,t} = stock_{i,t-1} + sales_{i,t-1} - sales_{i,t-T-1},$$

where i refers to the application case and T signifies the technical lifetime of the systems. The sales for each year t are derived from the HiEff-Biopower market study [6], and represent the technical sales potential for the full market segment that the HiEff-BioPower technology could address in future. The steps carried out to estimate this market potential were as follows: (1) estimation of the total current stock of CHP plants in the capacity range relevant for the HiEff-BioPower technology for the industry and district heating sectors, (2) assessment of the future market size according to the current stock, the renovation rates of the technologies, and the expected increase (or decrease) of the heat demand in each part of the market segment, and (3) estimation of the potential HiEff-BioPower sales in the future by considering the potential market shares of the technology compared to state-of-the-art biomass technologies providing heat and electricity (determined by a benchmarking analysis based on environmental and economic competitiveness). The final market study identified three different projections (high/medium/low) for the technical sales potential. This paper focuses on the medium sales projection exclusively. The assumption concerning the technical lifetime T is resulting from the HiEff-BioPower system development. Decommissioned appliances are assumed to be replaced and lead to additional sales.

To analyse the aspects illustrated in the preceding section, the impact assessment model generates (among others) the following outputs for every year t until 2050, each technology scenario and each application case:

- GHG emissions in CO_{2eq}/year resulting from fuel and grid electricity consumption, respectively
- TSP, CO, OGC and NO_X emissions resulting from fuel and grid electricity consumption, respectively
- Fuel and grid electricity consumption

The heat demand differs between the defined application cases, but is similar among the four technology scenarios for each application case. Furthermore, all scenarios presume that the typical nominal output of appliances in Europe needs to decrease by about 2% per year as expected effect of improved insulation of the buildings due to the EU Energy Performance of Buildings Directive ("EPBD"). The amount of fuel necessary to meet the heat demand, the electricity production and the net grid electricity consumption, which may be negative, were derived during the techno-economic analysis for each technology scenario. The techno-economic analysis in the project was based on inputs from the manufacturing partners regarding expected investment and operation costs as well as on experiences from the scientific partners regarding the expected performance data and emissions.

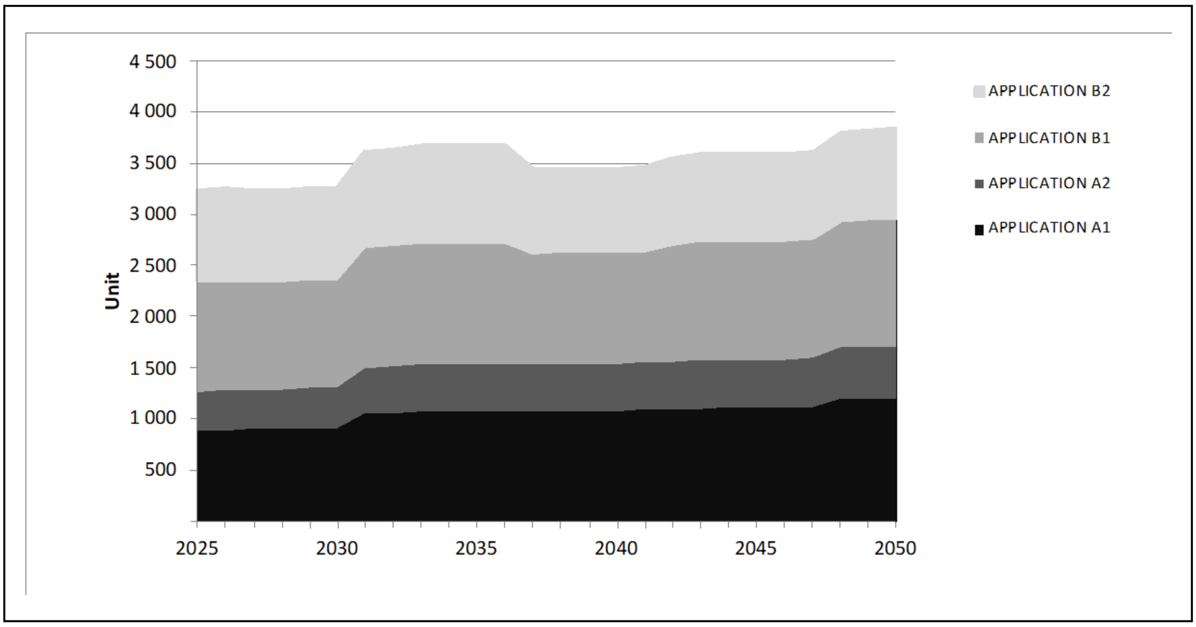
The defined parameters have been compared with available data from comparable state-of-the-art CHP systems. Based on this, the impact assessment model calculates greenhouse gas and air pollutant emissions arising from fuel and grid electricity consumption. The emission intensities needed for this calculation were also derived from the techno-economic analysis or taken from additional literature. The emissions of the state-of-the-art technology BB_WC are based on the emission limits according to the Austrian labelling UZ37 for wood chip boilers [7], while the emissions regarding the GE_WP are referred to the emission limits according to the German "Technical Instructions on Air Quality Control" [8] for gas engines. The greenhouse gas emission intensities for the fuels also take life cycle emissions into account. In the case of grid electricity, a general decrease of the emission intensity is to be expected. The GHG emission intensity of EU average grid electricity and its development in the future has been taken from the EU Ecodesign Impact Accounting [9].

Results achieved

Development of sales and stock

The sales numbers as illustrated in Figure 1 are total sales, including e.g. also sales that replace decommissioned end-of-life systems. Based on this, EU-wide stock data for the impact assessment is further calculated with a sales-driven stock model. In the following it is assumed that all sales are taken over by one or the other technology, in order to compare the potential total impact corridor of the different technologies considered for the relevant market segment. For the purposes of the impact assessment, stocks of new systems are calculated from a defined reference year (2025) onwards. This reference year is an assumption for a future market introduction, based on the final outcomes of the technology development at the end of the HiEff-Biopower project. Accordingly, potential historical stocks are not carried over, and the model then combines total sales data from the reference year onwards with average lifespans characteristic for each application to calculate stock data successively for each year of the simulation period, using the equation presented in the preceding section.

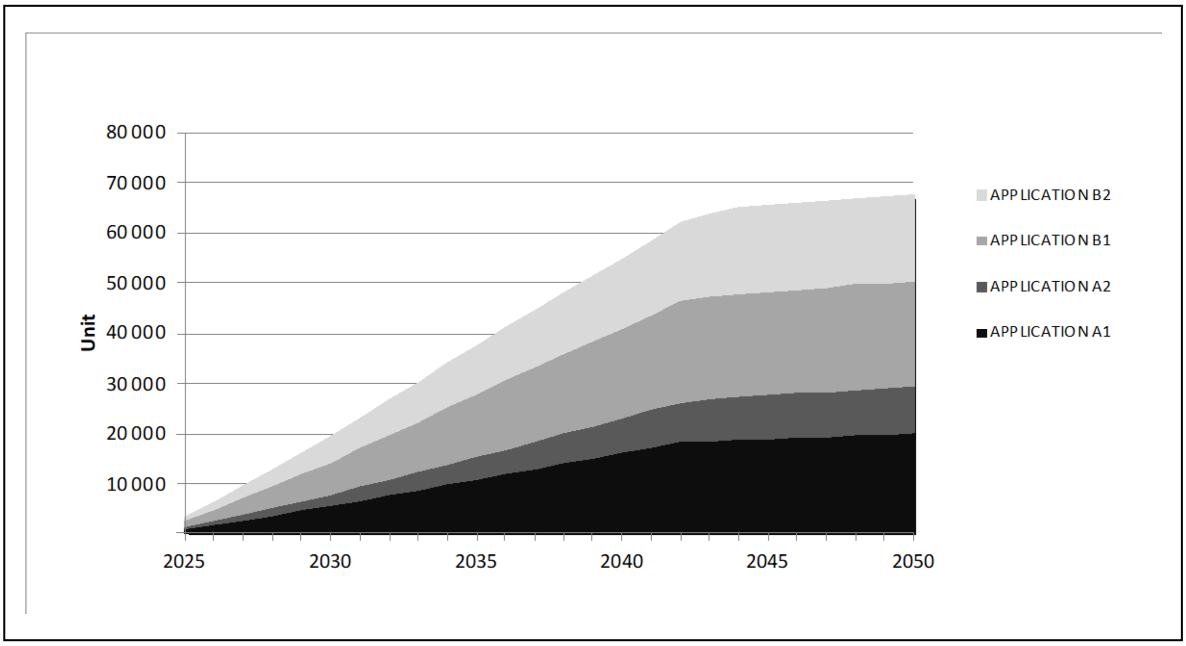
Figure 1. EU-wide development of sales for the four application cases until 2050



Source: Own illustration, based on HiEff-BioPower market study [6]

As can be seen in figure 1 and figure 2 for the considered cases, applications A1 and B1, closely followed by application B2, dominate the market in absolute numbers of potential sales and consequently in stock sizes. The medium sales scenario from the HiEff-BioPower market study [6] is represented here but the low and high sales scenarios present the same general pattern. Sales dynamics are similar in all applications with variability stemming from assumptions made on historical sale patterns in the market study. Cumulative sales lead to stocks increasing at a steady growth rate until about 18-20 years after 2025, when the growth rate strongly decreases because from that point onwards the sales do not solely add to the stock of new systems but also come to replace end-of-life systems installed after 2025. Stock levels in the EU (see figure 2) reach 19,846 units in application A1 and 9,407 in application A2 in 2050. Applications B1 and B2 technology stocks reach 21,094 and 17,277 units in 2050, respectively.

Figure 2. EU-wide development of the stock for the four application cases until 2050



Source: Own illustration, based on HiEff-BioPower market study [6]

Greenhouse gas (GHG) emissions

As described in the preceding section, GHG emissions are calculated by multiplying fuel and net grid electricity consumption with the respective emission intensities. Table 1 shows the fuel emission intensities used for modelling. According to the EU Ecodesign Impact Accounting [9], average EU-28 GHG emissions of electric power generation are assumed to decrease from 0.40 kg CO_2/kWh_{el} in 2015 to 0.26 kg CO_2/kWh_{el} in 2050. According to data by the European Environment Agency, in 2020 grid electricity emission intensities were about 0.08 kg/kWh higher than the EU-average in Germany and about 0.15 kg/kWh lower than the EU-average in Austria [11]. All scenarios use the EU-average for the grid electricity emission intensity and its projected future development. It can be expected that the variation within EU-member state grid electricity emission intensity will decrease in the future due to higher shares of renewables. Therefore, it is likely that modelling each scenario on the member state level would not lead to substantially different results.

Table 1. GHG emission intensities and net calorific value (NCV) of fuels

Fuel	**GHG** ($kgCO_{2eq}$/GJ fuel)	**NCV** (MJ/kg fuel)
Miscanthus pellets	11	16.2
Wood chips	4	12.4
Wood pellets	11	17.6

Source: EU Ecodesign Impact Accounting [9]

Overall, four technology scenarios are considered for each application: HiEff-BioPower technologies fuelled with wood chips or miscanthus pellets (HEBP_WC, HEBP_MP), a gas engine fuelled with wood pellets (GE_WP) and a traditional wood chip biomass boiler (BB_WC). The figures below also show that the stock volumes of heating systems first rapidly go up before plateauing, reflecting the assumptions made in modelling future sales and the expected technical lifetime of the technologies.

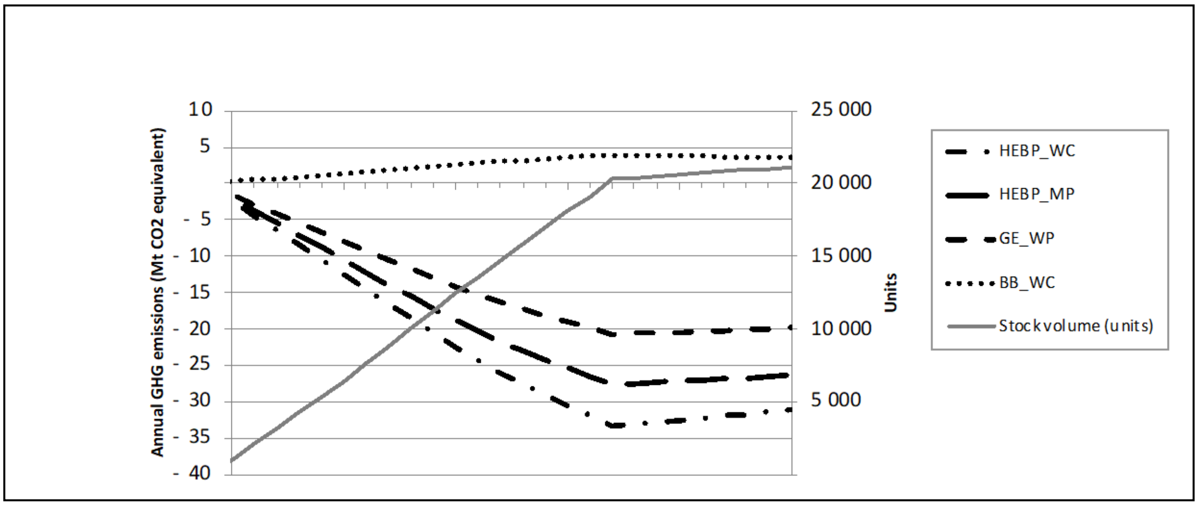
The scenarios with the new HiEff-BioPower technology using wood chips or miscanthus pellets help to save more GHG emissions than scenarios with the state-of-the-art conventional wood chip boiler and gas engine.

Avoided grid electricity GHG emissions are 5-6 times higher than direct emissions from fuel combustion for HiEff-BioPower with miscanthus pellets, and 13-15 times higher for HiEff-BioPower with wood chips. The difference comes from the fact that miscanthus pellets, as a more processed fuel, have a higher lifecycle GHG intensity than easy to produce wood chips.

Emissions from fuel combustion dominate total GHG emissions for the wood chip boiler in all applications (about 76% in 2050 in every application case). This technology scenario (because it does not displace grid electricity generation) also shows consistently higher emissions than the scenarios with the CHP technologies. For the gas engine CHP, avoided grid electricity GHG emissions are 2.3 to 2.5 times higher (in absolute values) than the direct GHG emissions from wood pellets combustion. The gas engine technology fuelled with wood pellets helps to avoid (through displaced grid electricity generation) about 60-64% of the amount of GHG emissions in 2050 that the HiEff-BioPower technology fuelled with wood chips would avoid. When the gas engine scenario is compared to the scenario with the HiEff-BioPower technology fuelled with miscanthus pellets, this value is between 75% and 79% in 2050. The wood chip biomass boiler generates mostly directly through fuel combustion about 12% (when wood chips are used as fuel) and between 14% and 16% (when miscanthus pellets are used as fuel) of the GHG emissions that the HiEff-BioPower systems help to avoid.

Regarding sales and stock volumes, applications A1 and B1, closely followed by application B2, dominate the market potentials. Applications B1 and B2, however, consist of larger systems (with higher thermal output) than A1 and A2. In addition, application B1 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part-load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the emission scenarios between applications. Application B1 presents the highest GHG emission levels and emission saving potentials (depending on the technology) in 2050 for all technologies considered. Then follows application B2, in which emission savings reach 44% (HEBP_MP), 46% (GE_WP) and 48% (HEBP_WC), respectively, of those seen in application B1 scenarios for the same technologies. The wood chip boiler scenario in application B2 is responsible for 52% of the emissions in 2050 as the same technology scenario in application B1. For the purposes of this paper, due to the highest emission levels and emission saving potentials, the scenario results with focus on application B1 will be presented and discussed more in detail (see following figures).

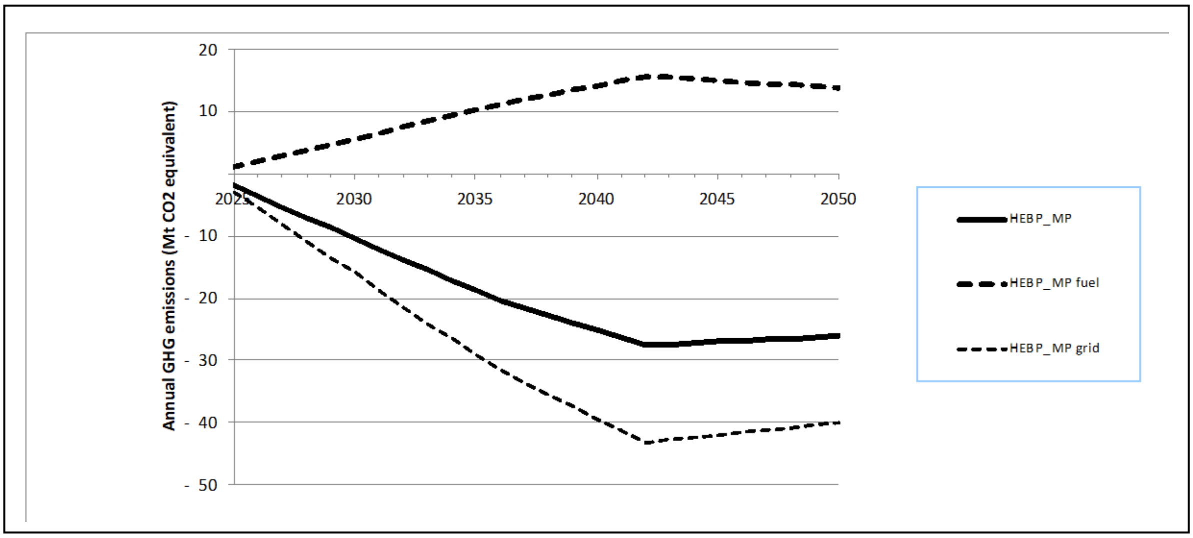
Figure 3. GHG emissions in the four technology scenarios for Application B1 (EU-28)



Source: Own illustration

The smaller systems in application A1 (but with the same 8,000 full load hours as in application B1) generate 19% of the emission levels and savings in application B1, consistently across technologies and types of emissions. Finally, application A2, characterized by the lowest market potential, small systems, and lower full load hours, reaches between 5% and 6% of the emission levels and savings in application B1. Exemplarily for application B1 (HEBP_MP), an additional graph shows in detail the contributions of fuel use and net grid electricity consumption in generating GHG emissions in the corresponding scenario (see figure 4). The terms "fuel" in the graphs refers to direct emissions resulting from biomass fuel use by the HiEff-BioPower systems. The term "grid" indicates net emissions from grid electricity generation (i.e., emissions from grid electricity actually consumed by the application case minus avoided emissions through the system's own gross electricity output).

Figure 4. Detailed GHG emissions for the HEBP_MP scenario for Application B1 (EU-28)



Source: Own illustration

Air pollutant emissions (TSP, CO, OGC and NO_X)

Air pollutant emissions (i.e. TSP, CO, OGC and NO_X) are calculated by multiplying fuel and net grid electricity consumption with the respective emission intensities. Table 2 presents the air pollutant emission intensities for the four technology scenarios BB_WC, GE_WP, HEBP_WC and HEBP_MP. The emission intensities used for EU grid electricity can be found in Table 3. Following the Ecodesign Impact Accounting [9], air pollutant emission intensities are assumed to remain constant until 2050.

Table 2. Air pollutant emission intensities for the technology scenarios

Emissions	**Unit**	**BB_WC**	**GE_WP**	**HEBP_WC**	**HEBP_MP**
TSP	(mg/MJ)	25	7	0	0
CO	(mg/MJ)	120	333	20	20
OGC	(mg/MJ)	4	0	0	0
NO_X	(mg/MJ)	100	167	0	0

Source: HiEff-BioPower techno-economic analysis

Table 3. Air pollutant emission intensities for grid electricity (EU-28)

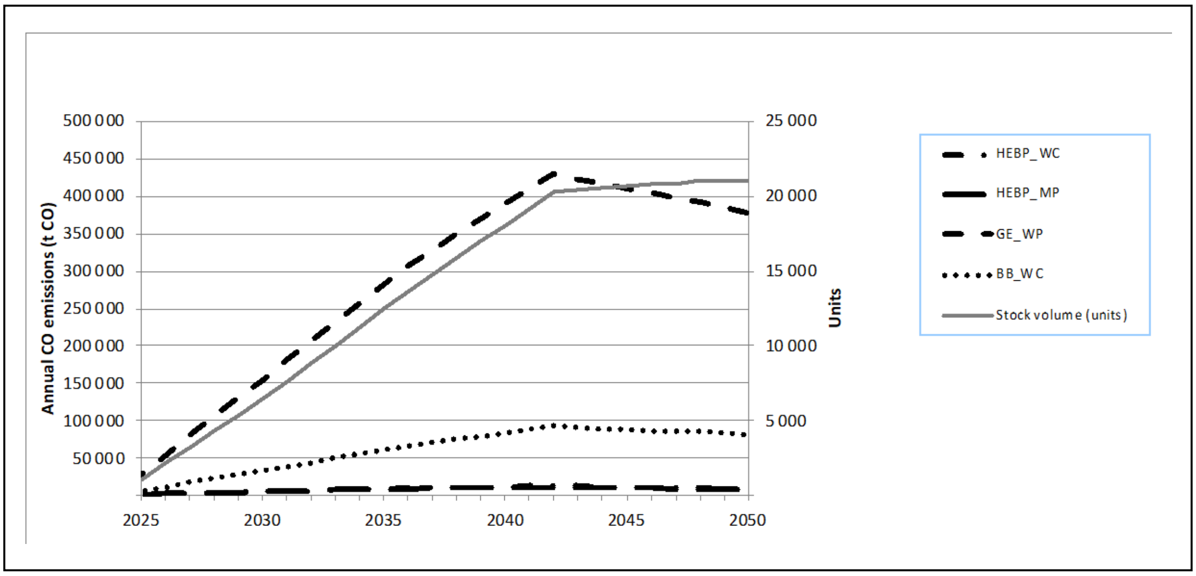
Emissions	Unit	Grid electricity generation (EU-28 mix)
GWP	kg/kWh	0.40
CO	g/kWh	0.11
OGC	g/kWh	0.01
TSP	g/kWh	0.02
NO_X	g/kWh	0.26

Source: GHG emissions from grid electricity based on [9]; non-GHG emissions from grid electricity are calculated, based on EMEP/EEA air pollutant emission inventory 2018

Total TSP, CO, OGC, and NO_X emissions are the result of contributions from solid fuel combustion and net electricity consumption. The latter means that emissions from grid electricity consumption are calculated as the difference between emissions from grid electricity actually consumed in each scenario and from grid electricity avoided through the gross electricity output of these CHP systems. As a result, net emissions from grid electricity consumption may be even negative, which indicates that grid electricity emissions have been avoided. Negative net emissions for HiEff-BioPower scenarios, in particular, result from vastly less emission intensive technologies (less fuel related emissions) further compensated by avoided emissions from grid electricity generation. The HiEff-BioPower systems show negative net emissions, except for CO. Net TSP emissions are positive in the gas engine scenarios. For this technology, OGC net emissions are negative while CO and NO_X emissions are positive and higher in the wood chip boiler scenarios, respectively. In any case, the new HiEff-BioPower technology scenarios show significant technical emission saving potentials compared to state-of-the-art conventional biomass boilers and gas engine CHPs. These results are sensitive to crucial technical parameters and other assumptions such as emission intensity of the different solid fuels used by different technologies. Further assumptions regarding the future development of grid electricity emission intensity and heat energy demand (driving thermal output, hence fuel requirements) are also very relevant for the overall behaviour of the model.

Independent of the application case or technology and all other aspects being equal, total stock emissions decrease in the long run when the stock's growth rate decreases or plateaus. The reason lies in the assumption that the typical size of systems in Europe decreases by 2% per year as expected effect of improved insulation and energy performance of buildings (based on EPBD, the EU Energy Performance of Buildings Directive). This rate then happens to be higher than the slowing rate of stock growth. Consequently, this means less fuel input, hence less fuel related emissions. According to the impact assessment results, Application B1 presents the highest emission levels and emission saving potentials (depending on the technology) for all technologies and types of emission considered. Application B2 comes second. Third are the smaller systems in application A1 (but with the same 8,000 full load hours as in application B1). Finally, application A2, characterised by the lowest market potential, small systems, and lower full load hours, reaches only a fraction of the emission levels and saving potentials observed in application B1. This follows from the sales and stock volumes where applications A1 and A2, closely followed by application B2, dominate the market potentials. Applications B1 and B2, however, consist of larger systems (with higher thermal output) than A1 and A2. In addition, application B1 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part-load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the emission scenarios between applications.

Figure 5. Total CO emissions and stock volume (Application B1, EU-28

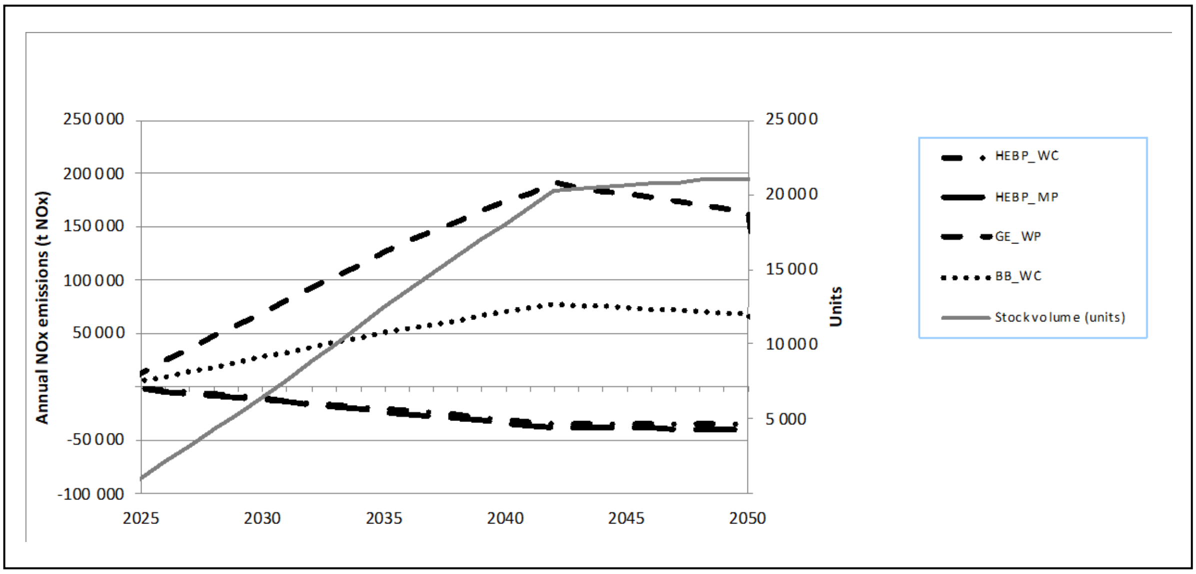


Source: Own illustration

Consequently, the scenario results with focus on application B1 will be discussed more in detail. The scenarios with the new HiEff-BioPower technology using wood chips or miscanthus pellets present significantly lower emission levels (for all four emission types) than scenarios with the state-of-the-art conventional wood chip boiler and gas engine. The emission totals presented in figure 5 and the following figures are the net sums of direct emissions from fuel combustion in the heating or CHP systems and indirect emissions from (EU-average) grid electricity generation.

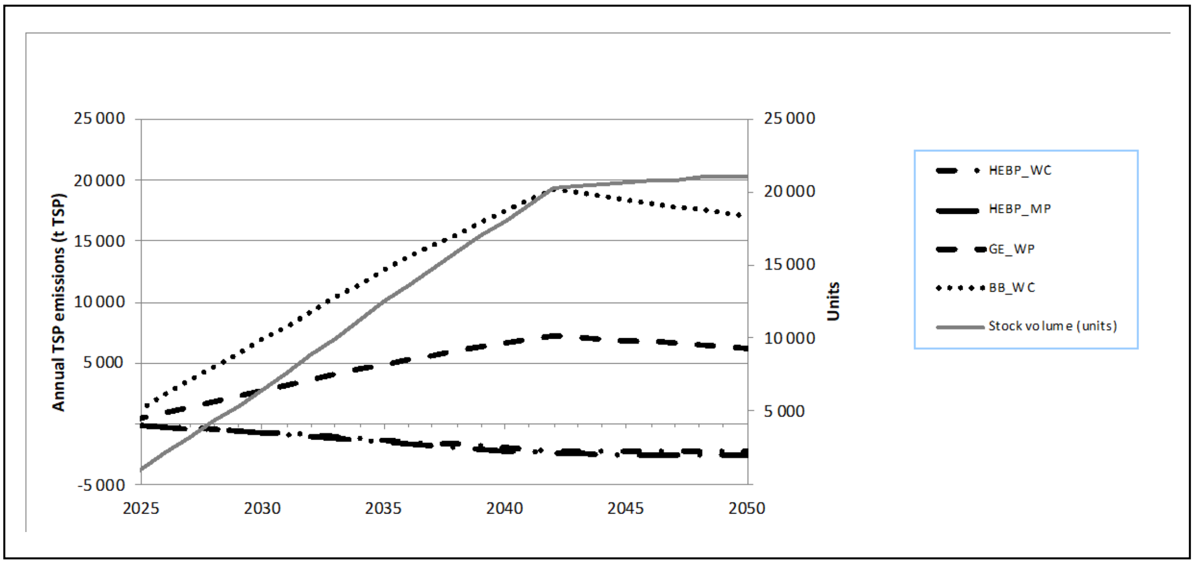
In all non-GHG emission categories, emissions from fuel combustion dominate the totals for the wood chip boiler (at least 99% in 2050). This technology scenario also shows consistently higher emissions than the one with the gas engine, except for CO and NO_X emissions (see figure 5 and figure 6). Emissions from fuel combustion (here wood pellets) dominate the net totals for the gas engine for CO and NO_X. Avoided grid electricity emissions reach 4% and 17% of the actual fuel combustion-related emissions (in absolute values) for CO and NO_X, respectively.

Figure 6. Total NO$_X$ emissions and stock volume (Application B1, EU-28)



Source: Own illustration

Figure 7. Total TSP emissions and stock volume (Application B1, EU-28)

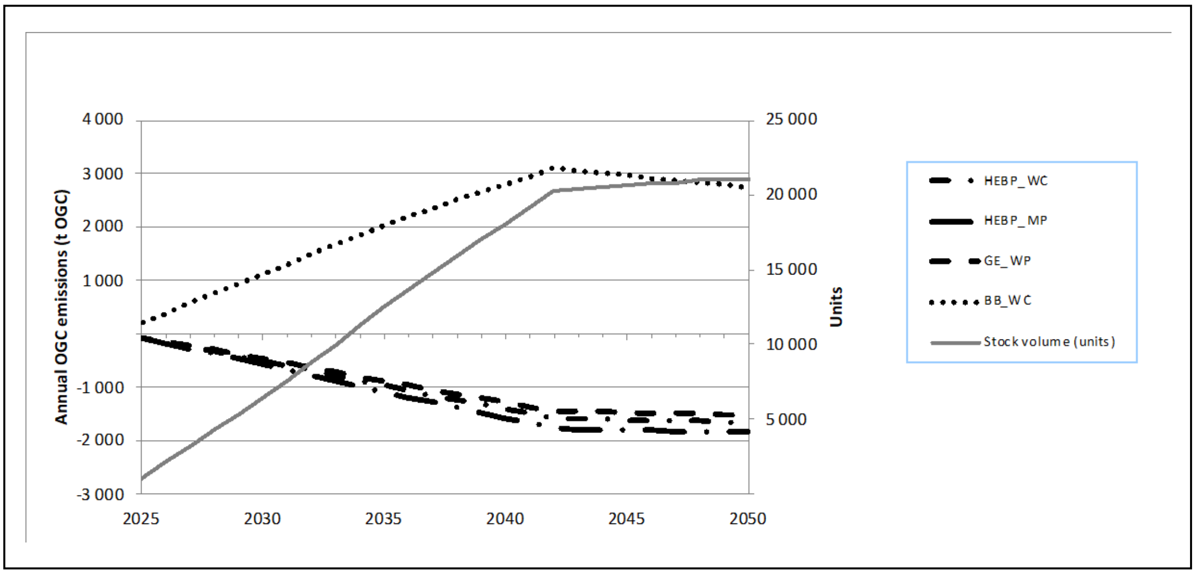


Source: Own illustration

In the case of TSP (figure 7), direct emissions from fuel combustion are almost four times the absolute value of avoided grid electricity TSP emissions in 2050. In the case of OGC emissions (figure 8), avoided indirect emissions are almost two orders of magnitude higher than the direct emissions due to fuel combustion. The gas engine technology fuelled with wood pellets helps to avoid (through displaced grid electricity generation) 82% of the amount of OGC emissions in 2050 that the HiEff-BioPower technology fuelled with miscanthus pellets avoids. This ratio is 91% when compared to the HiEff-BioPower technology fuelled with wood chips. For TSP emissions, the gas engine scenario has net "positive" emissions despite replacing grid electricity between two and three times higher than the absolute value of TSP emissions that are avoided in the HiEff-

BioPower scenarios. The gas engine scenario is also responsible for net positive emissions for CO and NO_X emissions. In the case of CO these emissions are between 40 and 50 times higher (in absolute value) than the emissions in the HiEff-BioPower scenarios in 2050.

Figure 8. Total OGC emissions and stock volume (Application B1, EU-28)



Source: Own illustration

The wood chip biomass boiler generates (mostly directly through fuel combustion) about 1.5 times the OGC and 1.7 to 1.9 times the NO_X emissions as the absolute value of emissions that are avoided in the HiEff-BioPower scenarios due to replaced grid electricity. The OGC emissions in the wood chip biomass boiler scenario are about ten times higher than the OGC emissions in the HiEff-BioPower scenarios in 2050, while the TSP emissions in the wood chip biomass boiler scenario are about seven times the absolute value of the TSP emissions avoided in the HiEff-BioPower scenarios because of replaced grid electricity.

Fuel and grid electricity consumption

Following the "efficiency first principle" [10], using and converting energy as efficient as possible is among the most important goals of the European Union's energy policy. The different technologies analysed in this impact assessment also show variations with respect to their total annual efficiency. Table 4 illustrates the total annual efficiency levels for the different technologies and application cases. The total annual efficiency determines the fuel consumption reflected in the technology scenarios. Results for the total fuel consumption of applications A1, A2, B1, and B2 presented in the subsequent figures follow each application's and technology's stock dynamics. In all four applications, fuel consumption first increases with the growing stock of appliances. It then starts to decrease, around 2043 for application A1 and B1 and around 2045 for applications A2 and B2, due to the different technical lifetimes assumed for the corresponding technologies. The rate of stock growth starts decelerating at those periods because new systems not only add up to the stock but also replace end-of-life systems that were installed in and after 2025.

Table 4. Total annual efficiency levels for the different technologies and application cases

	BB_WC	GE_WP	HEBP_WC	HEBP_MP
Application A1	81%	76%	81%	81%
Application A2	81%	74%	79%	80%

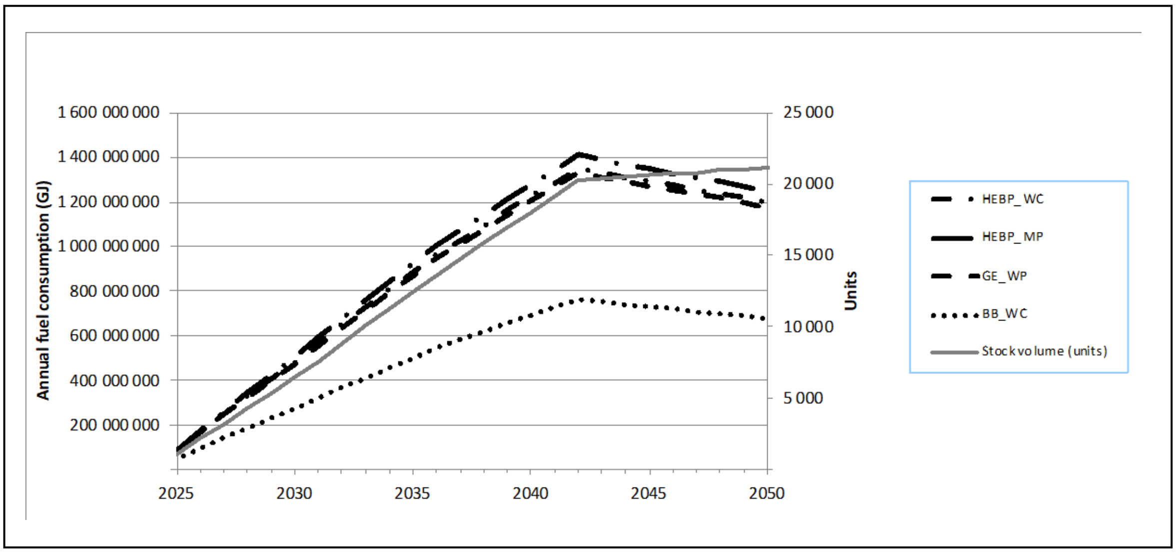
Application B1	81%	76%	81%	81%
Application B2	81%	74%	79%	80%

Source: HiEff-BioPower techno-economic analysis

The reason why fuel consumption then also decreases in the different applications lies in the assumption that the typical size of heating systems in Europe decreases by 2% per year as expected effect of improved insulation of the buildings (based on EPBD). This rate then happens to be higher than the slowing rate of stock growth, resulting in lower fuel input in absolute terms. Based on the model results, the calculated solid fuel consumption in 2050 is highest for application B1, followed by applications B2, A1, and A2. Application B1 also has the largest stock of installed systems in 2050, followed by A1 and B2 (in that order). Applications B1 and B2 consist of larger systems (with higher thermal output) than A1 and A2. In addition, applications A1 and B1 register 8,000 full load hours against 5,000 for application A2 and B2 (plus 2,000 part-load hours). The size of the systems explains why application B2 scenarios require more fuel than application A1 scenarios. Consequently, the following scenario results will be also discussed exemplarily and more in detail with focus on application B1 (see figure 9 and figure 10).

Comparing the technology scenarios with one another, within an application and across applications, mainly requires looking at respective total annual efficiencies and thermal outputs. In all applications, the wood chip boiler (BB_WC) presents the lower overall fuel use (see figure 9), which is to be expected because the technology consistently has the highest annual efficiency combined with the lowest thermal output and does not need fuel to generate electricity. Comparing fuel use for the HiEff-BioPower technology scenarios (HEBP) with fuel use for the gas engine (GE) scenarios shows that total fuel use of the stock is comparable across all application cases. The fuel use in the gas engine scenarios is a little lower due to the slightly higher total annual efficiency and the slightly lower thermal output at mixed load. The gas engine technology has the same level of thermal output as the wood chip boiler across all applications but a lower total annual efficiency.

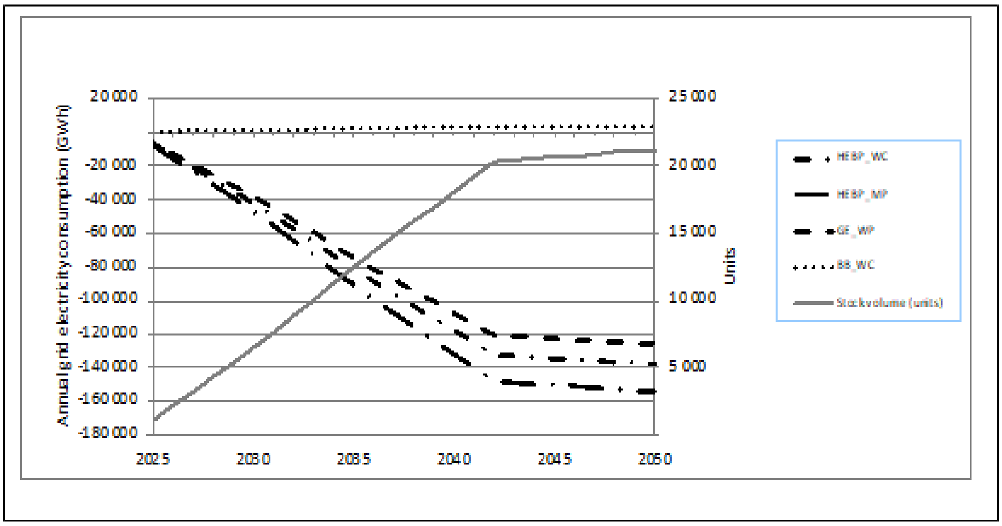
Figure 9. Fuel consumption in the four technology scenarios (Application B1, EU-28)



Source: Own illustration

For the wood chip boiler scenarios this equates the (limited) amount of electricity that the boiler requires for own function. For the gas engine and HiEff-BioPower CHP scenarios net grid electricity consumption is the difference between gross electricity production of the CHP system and the electricity needs of the corresponding technology scenario. In all applications, the HiEff-BioPower technologies present a higher gross electricity production than the gas engine. The HiEff-BioPower scenarios, with one exception, also have lower electricity consumption than the gas engine scenario. The HiEff-BioPower technology fuelled with miscanthus pellets consistently has a higher gross electricity production than the wood chip version, with a similar level of electricity consumption. In the end, the HiEff-BioPower scenarios using miscanthus pellets and wood chips feed more electricity to the grid than the gas engine, which explains why its curve runs lower in the negative part of the graphs than for any other scenario. In other words, the HiEff-BioPower scenarios displace more grid electricity through its own production than the gas engine scenarios. The absolute net electricity consumption values reflect the system and stock sizes. B1 and B2 applications use large systems, with more full load hours in B1. Application A2 uses small systems, coupled to the smallest stock size.

Figure 10. Grid electricity consumption (Application B1, EU-28)



Source: Own illustration

Conclusions

This paper presents results of the impact assessment of the use phase environmental performance of the new HiEff-BioPower CHP technology under development. The results are based on the final data available by the end of the project. Four application cases for space heating and domestic hot water supply were investigated: Application A1 covers "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-ups per year. Application A2 covers "small" CHP systems (200 kW_{el} / 260 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups per year. Application B1 covers "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base load district heating or heat supply for large companies in Central Europe (Germany, Austria) with around 8,000 annual full-load operating hours and up to three start-ups per year. Application B2 covers "large" CHP systems (1,000 kW_{el} / 1,300 kW_{th}) for base and medium load coverage (e.g. district heating, hotels, industry) in Central Europe (Germany, Austria) with around 5,000 annual full-load operating hours, 2,000 part-load operating hours, and up to twelve start-ups. Furthermore, two variants of the HiEff-BioPower system (fuelled with wood chips and with miscanthus pellets, respectively) are compared to a state-of-the-art conventional biomass boiler fuelled with wood chips and a state-of-the-art CHP gas engine system fuelled with wood pellets. The analysis includes effects of putting these four technologies on the entire European market until 2050. Thereby, emissions (GHG, TSP, CO, OGC, NO_X), fuel and net grid electricity consumption have been taken into account.

All absolute quantities (of emissions etc.) presented in this report should be interpreted in the context of a technology still under development. At this stage, it was important to understand the dynamics of the different application cases to be analysed and their sensitivities to technical parameters and other modelling assumptions. This kind of reasoning will inform both future development of the impact assessment tools and support decision-making regarding the general direction of the technology development and deployment. The modelling results help to identify the main emission drivers for the different technologies considered. In all CHP technology scenarios (HiEff-BioPower and gas engine), greenhouse gas emissions are driven by grid electricity consumption and since CHP technologies generate their own electricity, use part of it but feed most of it to the grid, avoided emissions from grid electricity quickly overcompensate direct GHG emissions from fuel use in these scenarios, meaning that net GHG emissions are actually negative. In the wood chip boiler scenario, on the other hand, greenhouse gas emissions are driven by fuel and grid electricity consumption.

Regarding CO, OGC, TSP, and NO_X emissions, whether solid fuel combustion or indirect emissions from grid electricity generation is the main driver depends on the technology and the type of emissions. The HiEff-BioPower systems show negative net emissions, except for CO where direct emissions from fuel combustion are higher than avoided emissions from electricity generation. In any case, the new HiEff-BioPower technology scenarios show significant technical emission saving potentials compared to state-of-the-art conventional biomass boilers and gas engine CHP. These results are sensitive to crucial technical parameters such as emission intensity of the different solid fuels used by different technologies. Further assumptions regarding the future development of grid electricity emission intensity and heat energy demand (driving thermal output, hence fuel requirements) are also very relevant for the overall behaviour of the model.

Regarding sales and stock volumes, applications A1 and B1, closely followed by application B2, dominate the market potentials. Applications B1 and B2, however, consist of larger systems (with higher thermal output) than A1 and A2. In addition, application B1 registers 8,000 full load hours against 5,000 for application B2 (plus 2,000 part-load hours). These underlying aspects of the model amplify the differences in potential market sizes when comparing the emission scenarios between applications. Application B1 presents the highest absolute emission saving potentials (depending on the technology) for all technologies and types of emission considered. Application B2 comes second. Third are the smaller systems in application A1 (but with the same 8,000 full load hours as in application B1). Finally, application A2, characterised by the lowest market potential, small systems, and lower full load hours, reaches only a fraction of the emission levels and saving potentials observed in application B1.

Considered together, all the insights gained give some meaningful indications on the most prominent aspects to be considered for the further long-range HiEff-BioPower system design and policies aimed at supporting such new technologies. The considerable reductions of air pollutant emissions that this technology makes possible mean that this type of new biomass fuelled CHPs can contribute significantly to reaching the European Union's energy and clean air policy goals by using residual biomass that otherwise would not be used at all. Furthermore, if the market potentials for the large systems (applications B1 and B2) can be fulfilled, any further improvement in the HiEff-BioPower design could have significant additional positive effects.

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Evaluation of the environmental benefits of energy management systems based on a realistic classification of French households - application to heating management systems

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Abstract

The development of home automation systems requires more environmental assessments to be consistent with policies aiming at reducing domestic energy consumption. This work makes an original contribution to the literature by presenting a methodology for finding an environmentally optimal hardware selection strategy. It is applied to case studies that are representative of household and housing situations in France. Assessing the environmental benefits of energy management systems raises two major issues: the estimation of the environmental impacts of the systems and the calculation of the heating energy consumption. In this work we investigate the environmental impacts in terms of greenhouse gas emissions (in $kgCO_{2,eq}$) and primary energy consumption (in kWh_{pe}). We propose to quantify the environmental benefits of such systems by balancing the life cycle impacts of the added control system against the associated reduction in heating requirement. The simulation of the heating requirement is performed using the dynamic thermal simulation software STD-COMFIE. We use household, housing and behavioural archetypes from the literature, which allows us to study fictitious households representative of segments of French households. The methodology for calculating environmental benefits is applied to three case studies with four different heating control systems. This paper concludes that there is a system minimising the impacts depending on the case study and the observed impact. All in all, a more complex management system systematically improves thermal outcomes but does not necessarily reduce the environmental impacts.

Abbreviations	
EB	Environmental Benefits
GHG	Greenhouse gases
HHBS	"Household - Housing – Behaviour" Situation
HMS	Heating Management System
Symbols	
I_{cons}	Vector (2x1) of environmental impacts associated with the heating consumption, for a given household, dwelling, behaviour, and heating management system (in primary energy and GHG emissions)
$I_{invested}$	Vector (2x1) of environmental impacts associated with the use of a heating management system during its life cycle (in primary energy and GHG emissions)
EB_{em}	Environmental benefit: GHG emissions avoided
EB_{pe}	Environmental benefit: Primary energy consumption avoided
P_i	Hardware selection strategy, $i \in [1,2,3,4]$

I. Introduction

According to the Energy and Climate Act, France commits to being carbon neutral by 2050 [1]. In that regard, the building sector offers particularly promising energy savings and emissions-cutting prospects since it accounts for roughly 15% of national GHG emissions and 44% of the national final energy consumption [2]. Recent policies aim at improving the energy efficiency of buildings and their energy consumption systems through financial packages (eco-PTZ), building regulations (RT 2012, RE 2020) and labels (DPE, E+C-). Nevertheless, the housing stock in France is still mostly composed of non-renovated buildings [3]. Moreover, the annual renovation rate of the housing stock is well below the recommended target set by the Energy Performance of Buildings Directive (EPBD) set to achieve the 2050 neutrality objectives (1.7% of the stock against 3% recommended). A complimentary solution would be the addition of suitable energy management systems. The management of heating, ventilation, and air-conditioning systems, which account for almost 40% of energy consumption on average, could result in savings of 14% [4]. However, there are many systems available on the market. The NF EN ISO 52120-1 standard provides a typology of control systems and a methodology to determine the energy saving potential for each level of automation. In addition, each management system has an environmental footprint through its grey energy, the raw materials used in its manufacture and the energy it consumes. The environmental impacts of these systems over their entire life cycle are not systematically assessed and weighed against the energy savings they bring. In addition, there are many management systems available on the market making it difficult for a household to choose a suitable solution based on environmental criteria. Thus, a methodology to evaluate the environmental benefits of management systems would help to target the household-housing situations where these systems are likely to be used. On a larger scale it would also provide useful information to decision-makers to reduce the environmental impacts of the building sector.

II. Literature review

1. Environmental impacts of HEMS

To the knowledge of the authors, Van Dam et al. [5] were the first to study the environmental benefits of using energy management systems. They consider that a system is relevant only if the energy savings it achieves (e_{saved}) are greater than the amount of energy consumed during its entire lifecycle ($e_{invested}$). The payback time is defined as the time until both quantities are equal ($e_{invested} = e_{saved}$). It depends on the type of energy management system, its usage, and the dwelling where it is installed. The energy invested ($e_{invested}$) is independent of the household and the dwelling and can be determined by a life-cycle analysis. Within this perspective, Nicolas et al [6] investigated whether the full automation (21 connected electrical sockets, smart thermostat, smart meters) of an average Finnish household was worthwhile from an environmental point of view when considering the whole life cycle of the appliances. They compare the energy savings and impacts of the energy management systems over a 5-year lifetime. The environmental benefits (EB) considered are the greenhouse gas emissions (EB_{em} in $kgCO_{2,eq}$) and the primary energy consumption (EB_{pe} in kWh_{pe}). Eventually the authors calculated a negative payback time, concluding that full automation is not cost-effective in terms of energy consumption and GHG emissions. Therefore, a careful and well-informed selection of energy management systems is required. For instance, the authors stated later in [7] that a single smart meter providing feedbacks to home occupants could be more profitable. This suggests that there is an optimal hardware selection strategy that minimises the environmental impacts associated with heating and the automation system over the whole life cycle. It appears that only a limited number of articles have questioned the EB of heating automation. Bracquené et al. [8] determined the minimal energetic gain that a smart thermostat must generate in order to compensate the invested impacts over the entirety of the life-cycle for a given theoretical heating need and a given time frame for the return over investment. The study provides interesting orders of magnitude for these systems, but it does not provide an assistance for choosing equipment, which requires an explicit simulation of energy consumption. To address this issue, we simulate heating energy consumption in different houses and for different equipment combinations.

2. Simulation of domestic energy consumption for heating

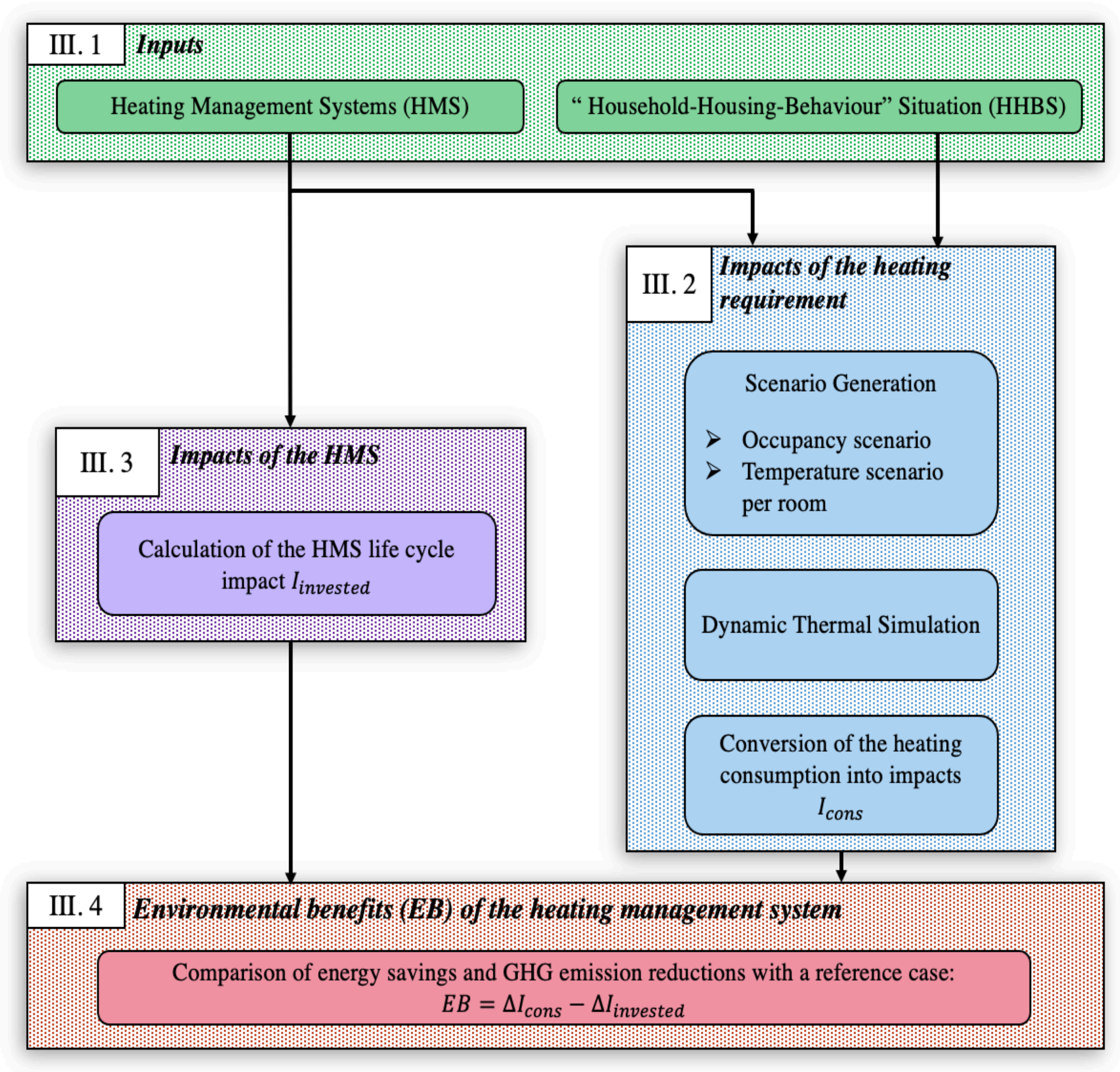
Simulation of heating requirements is very often discussed in the literature and modelling by equivalent electric circuits is used both by researchers and consulting engineers. The 3R2C model presents a thermic response relatively close to real observed response [9]. Based on the improvement of the 3R2C model, several software have been developed to model the thermal envelope of a housing [10]. However, a large body of research has documented the fact that space heating consumption depends significantly on the household, the equipment and the behaviour [11]. Four main approaches have been identified in the literature to integrate these dimensions into heating demand models. The first one consists in considering an average household derived from statistical studies. Nicolas et al. used this approach in their different works [6,7,12]. Nevertheless, the heating needs are very sensitive to these parameters and this model does not allow to conclude on the profitability of a management system for real cases. The second approach is based on a probabilistic approach: it assigns equipment and behaviour to households according to their characteristics. The sequences of behaviour are then simulated using a Markov chain, constructed from time use surveys [13,14]. However, its implementation is complex, the coherence of the behaviour scenarios and the interactions are not considered, and the data sources are often quite heterogeneous. Thirdly, multi-agent approaches make it possible to account for interactions between humans and with technical systems. These models allow to test behavioural hypotheses and to simulate realistic consumption curves on a very fine time scale [15]. This approach seems to be adapted to our study, however the very heavy development and the need for very rich data do not allow us to consider its use. Eventually, the last approach consists in the use of behavioural archetypes stemming from consumption data surveys [16] as well as daily logbooks [17]. This archetypal approach reduces the number of simulations because the space of behaviours is reduced to a limited number of homogeneous segments, represented by a single understandable archetype. Overall, this type of approach seems adequate for assessing the environmental effectiveness of management systems because it allows for a realistic, explainable, and disaggregated simulation of the heating consumption of heterogeneous and representative households and houses.

This work presents a methodology for determining the EB of a heating management system based on dynamic thermal simulation and on household, building and behaviour classifications. It will be applied for four heating management systems to three French household-housing-behaviour situations (HHBS).

III. Methodology

The methodology developed proposes to evaluate the EB of a Heating Management System (HMS) quantified in kilowatt-hours of primary energy (kWh_{pe}) used and in kilograms of CO_2 equivalent ($kgCO_{2,eq}$) emitted for a given French household situation over the entire life cycle of the system. It is based on a comparative analysis of the impacts of the management system and the reduction in consumption of the dwelling due to the installation of the system. The methodology is presented in figure 1 and detailed in the following paragraphs.

Figure 1. Synopsis of the methodology to determine the environmental benefits (EB) of a heating management system (HMS) for a given household, dwelling, set of behaviour, and HMS



1. Input

1. Household – Housing – Behaviour

a) Parameters for thermal model

To calculate estimates of energy requirements for heating, we mobilized a set of parameters describing the household, the dwelling, and the user behaviour. The parameters are listed in table 1. In an iterative logic, we have chosen to include first only the behaviour of the inhabitants related to the regulation of the heating appliances. The list of parameters is not exhaustive: other parameters could be integrated in future work such as the use of equipment, the opening and closing of windows, etc.

Moreover, from one case study to another, the whole parameters can differ, and, therefore, it is important to have access to classification grouping enough of these parameters to model several thermal situations

Table 1. Parameters defining a household - housing - behaviour situation (HHBS) from the archetype association. These parameters are then used to construct the occupancy and temperature scenarios and to simulate the heating requirement (see section III.2). The parameters are taken from the classification work of Lévy et al [18], the TABULA project [19] and Heinrich et al. [20].

Parameters	Household archetypes [18]	Housing archetypes [19]	Behavioural archetypes [20]
Energy used	X		
Type of dwelling	X	X	
Composition of the household	X		
Housing area (Rural/Urban)	X	X	
Surface of the dwelling	X		
Layout		X	
Construction period	X	X	
Materials of the Thermal Envelope		X	
Windows		X	
Doors		X	
Temperature setpoint			X
Regulation of the dwelling temperature			X
Presence at the dwelling			X

b) Household – Housing – Behaviour archetypes association

In this paper we exploit the knowledge built up in the literature on housing, household, and behavioural archetypes to perform fine simulations of hypothetical dwellings and households that are representative of frequent real cases. This type of archetypal modelling has already been undertaken for example by Diao [17] to perform a bottom-up housing consumption simulation and by Ben and Steemers [16] who have exploited archetypal behaviour to propose tailored solutions for each segment. The main difficulty of this approach lies in the articulation of the different works which each provide information on different types of housing. We have chosen to rely first on the work of Lévy et al. [18] who constructed 10 profiles of energy use in France, that are attached to typical households and dwellings. The profiles are based on micro-data from 2002 to 2006 National Housing Surveys. We have selected 3 of them for our study which are both different in terms of household composition and dwelling size and which are quite frequent (>10% in proportion). They are presented in table 2. For each of the profiles, we use the characteristics of the dwelling (age, type, size) to match one of the 40 buildings of the French building typology from the TABULA project [19]. The TABULA project is European project classifying the national housing stock of 13 EU member countries. Each building archetype provides detail of the materials typically used in its construction. Furthermore, based on the study of empirical behavioural data from 2010 collected from 1950 households in the Ile de France region, Heinrich et al. constructed 7 archetypes of domestic behaviour. These archetypes allow a qualitative description of average behaviours (e.g. high presence during weekdays; numerous or non-existent thermal regulation behaviours; high or much lower than average equipment levels). They described the behavioural logics associated with these sets of behaviours and the profiles of the most frequently associated households and dwellings. By associating the characteristics, we assigned heating temperatures, a level of thermal regulation, and a level of presence for each of the 3 profiles. A summary of the sources used for each of the simulation parameters is given in table 1.

In summary, we associate a household profile with a housing archetype but also with a behaviour archetype, thus defining a household housing behaviour situation (HHBS). From the 3 profiles, we construct 3 case studies (HHBS1, HHBS2, HHBS3). The households and dwellings are described in table 2. In addition, the details of the thermal parameters defining each household – housing – behaviour situation is summarised in Annex 1.

Table 2. Archetypes of dwellings, households and energy used studied for the three case studies. Archetypes are described in the work of Lévy et al [18].

# HHBS	**Proportion of French households represented by the archetype** according to Lévy et al. [18]	**Description of the profile** (household, dwelling, energy used for heating)
1	22.2 %	Young couple; tenants in a flat smaller than 70 m^2, built after 1975 in an urban area. Using electricity for heating.
2	13.2 %	Young working-class middle-income single people; tenants of a flat with 4 rooms built between 1949 and 1974 in an urban area. Using gas for heating
3	26.3 %	Middle-income families aged 40-59; owner occupiers of a house larger than 70 m^2 built before 1948 in a rural area. Using electricity for heating

2. Heating Management Systems

In this work, the environmental benefits of several hardware selection strategies for given dwellings, households and behaviour are compared. The objective of this sub-section is to select heating management systems that are representative of the diversity of the current market of HMS. In the PHEBUS survey carried out in 2013 in France on a representative sample, only 25% of households declared not to have temperature control equipment [21]. While the thermostat is a mature and widely spread invention, three notable improvements remain: the programmable thermostat, thermostatic valves and intelligent thermostats. It is important to remember that although designers claim that every technological development improves energy savings, the results of the studies are rather scattered. For example, a study on programmable thermostats carried out in the United States in Seattle on 2300 households found that the effective gain of a programmable thermostat is 9% [22] while another study shows that it does not bring more energy savings than a thermostat whose set point is managed manually [23]. Also, some researchers believe that a home with a programmable thermostat consumes more energy than a home with a manual thermostat [18]. Finally, the gain of these devices is very variable according to each situation they are added and to the author's knowledge, no study compares these systems considering their whole life cycle for a given HHBS.

Four hardware selection strategies (P_i) are constructed for the application of the proposed methodology (table 3). In each strategy, several systems are mobilised (thermostats, temperature sensors, valves). The strategies are distinguished by the programmable or non-programmable nature of the heating, by the fact of managing the heating by room or not, and by the capacity to integrate the occupation of the rooms or not. As an example, scenario P_4 corresponds to a system that regulates domestic heating per room by perfect occupancy detection.

Table 3. List of the hardware selection strategies P_i

Symbol	Description of the management systems carried out.
P_1	Room thermostat with manual setpoint change
P_2	Pre-programmable room thermostat
P_3	Pre-programmable room thermostat + one pre-programmable thermostatic valve per room
P_4	Room thermostat + Thermostatic valves per room. Control by room occupancy detection

These choices of equipment can actually offer varying performance between manufacturers, particularly due to the type of management algorithm used, which significantly affects the potential energy savings

[24]. However, these management algorithms are not currently considered in this study. Thus, the hardware selection strategies P_i model increasing automation levels that are a good approximation of those proposed in the standard NF EN ISO 51220-1.

2. Impact of the heating requirement

1. Dynamic Thermal Simulation

For this work, the STD COMFIE software [25] was chosen, which is a dynamic thermal simulation software for buildings based on a multi-zone approach. For each thermal zone the following state model is solved:

$$\dot{T} = AT + BU$$
$$Y = JT + GU$$

With :

T: temperature vector

U: external variables

B: command matrix

A, J & G : observation matrix

As the control algorithms of the management systems are not considered, no temperature feedback loop is implemented. Two cases are therefore possible: if a room is equipped with a temperature sensor, the instantaneous heating power is determined in such a way that the desired room temperature is maintained. The state model is then reversed. If a room is not equipped with a temperature sensor, the instantaneous heat output is equal to the area output of the room where the measurement point is located multiplied by the area of the room not equipped. This assumption allows modeling the adaptation of the heating power to the surface of the rooms respecting a uniform power set point. Finally, the thermal simulation requires a temperature scenario per room as input. In this work, neither solar heat gain nor internal heat gain are considered. Furthermore, the outdoor temperature data used for the simulation are conventional data linked to regulatory calculations (RT2012) and representative of the climate in Trappes (climate zone H1a, semi-continental).

2. Scenarios generation

a) Occupancy scenario

The occupancy of the dwelling has a major influence on the heating requirement [26]. The occupancy scenario for the HHBS is based on a stochastic model whose parameters are drawn from the "Presence at the dwelling", variable of the behaviour archetypes. Thus, the occupation of the dwelling is modelled at the household level. Three types of event are taken into account to model the occupation of a weekday: leaving the dwelling, returning to the dwelling and going out in the evening. The hours associated with each event is calculated each day using a normal distribution parameterized according to the "presence in the dwelling" variable specific to each case study. For active households, the departure and return times are centered on 8am and 6pm respectively (figure 2), while the retired household has a longer duration of presence in the home (absence between 10am and 4pm). Moreover, evening and weekend absences follow a Bernouilli distribution, the parameter of which also depends on the household considered. This relatively simple model does not allow for a detailed modelling of the mobility of each member of the household, but it does allow for the reproduction of heterogeneous occupation trends. A possible improvement of this model is the calibration of the occupancy parameters on the time-use surveys.

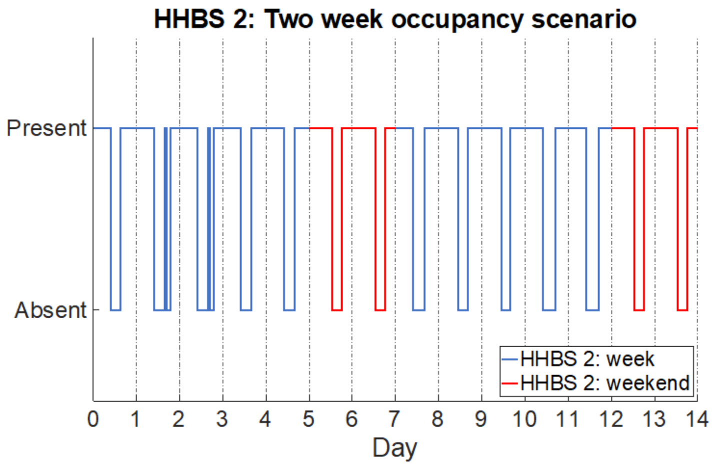
The stochastic parameters for the three household – housing – behaviour situations selected are in table 4.

Table 4. Parameters used to generate the occupancy scenario for the three selected situations

#HHBS	1	2	3
Departure law (h)	$\mathcal{N}(8\,,0.5)$	$\mathcal{N}(10\,,0.5)$	$\mathcal{N}(8\,,0.5)$
Returning law (h)	$\mathcal{N}(18\,,0.5)$	$\mathcal{N}(16\,,0.5)$	$\mathcal{N}(18\,,0.5)$
Evening absence probability	0.6	0.2	0.2

Weekend departure probability	0.4	0.05	0.05

Figure 2. Example of a two-week occupancy scenario.



b) Temperature scenario

The simulation of the heating requirement in STD-COMFIE requires the specification of a temperature scenario for each room. These scenarios depend on both the behaviour of the household and the hardware selection strategy used. They are generated in three steps.

Firstly, a temperature scenario “behaviour scenario” (BS) is constructed for each room. In this scenario, the temperature oscillates between 3 temperature levels. The heating temperature is deduced from the variable "setpoint temperature" of the behaviour archetypes. In particular, it is set in relation to average of the declared heating temperature (20.3°C). This average value was obtained from Heinrich et al. on the ENERGIHAB dataset which describes the domestic behaviours of 1950 in the Île de France region (2010) [27]. Also, depending on the level of the variable "regulation of the dwelling temperature", a “temperature reduction” event of 3°C is possible during an absence and of 2°C at night. These events are generated according to two Bernoulli models whose parameters are specified in table 5. Thus, a draw is made when the household leaves or when it goes to bed. If it is successful, the HMS set point is lowered. Based on the occupancy scenario and the behaviour parameters, a temperature scenario is generated for each room.

Secondly, for a given HHBS and P_i, an "automat scenario" (AS) is calculated for each room and represents the temperature control that would be imposed by a managing system only. Consequently, the shape of the AS temperature scenarios depends on the technical possibilities allowed by each of the P_i hardware selection strategy :

- P_1: Constant temperature scenario
- P_2: Periodic temperature scenario
- P_3: Periodic temperature scenario
- P_4: Temperature scenario that perfectly matches the occupancy scenario

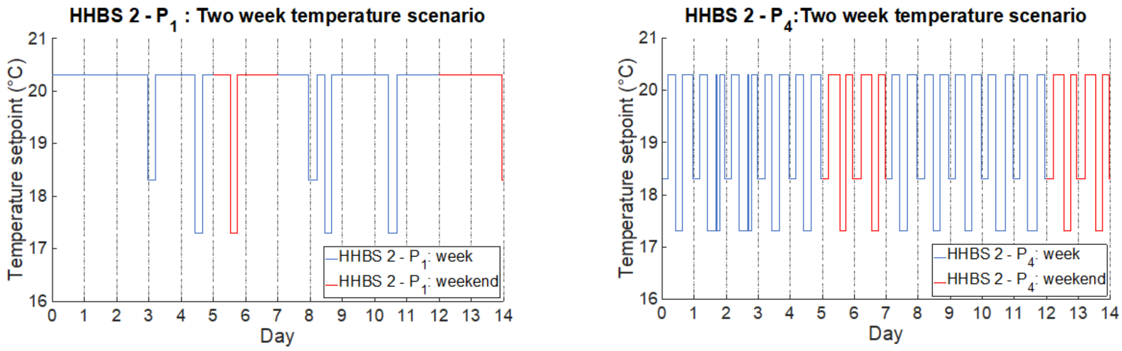
Thirdly, the superposition of the two scenarios is done, considering that when there is a conflict with the automatic management of the HMS, priority is given to the occupants. At each moment and for each room, the temperature set point is thus equal to the minimum between the two set points BS and AS. An example of two-week temperature scenarios during the heating period is shown in figure 3.

This modelling approach consists in working not at “constant comfort” but at “constant behaviour”. As an example, we assume that the probability of lowering the heating during an absence or during the night is considered as independent of the HMS. This approach is supported by empirical research which shows that replacing a management system (manual thermostat) by a more sophisticated system (pre-programmed thermostat) does not change the HMS-occupant interaction [28].

Table 5. Parameters used to generate the temperature scenario for the three HHBS.

#HHBS	1	2	3
Temperature setpoint (°C)	19	20.3	22
Probability of a "temperature reduction" event.	0.8	0.2	0.2

Figure 3. Example of two-week temperature scenarios during the heating period for two combinations HHBS2-P1 on the left, HHBS2-P4 on the right



3. Converting heating consumption into impacts

The thermal simulation is used to determine the annual net heating requirements of the house. In order to compare the impacts over the lifetime of the heating management system, these heating requirements must be converted into impacts (kWh_{pe}, $kgCO_{2,eq}$). This conversion is affected by two parameters: the efficiency of the heating system and the type of energy used to heat. The assumption is made to use the primary energy and emission conversion factors from the carbon base developed by ADEME for the year 2019 [29].

The impact vector of annual heating requirements for a given management system and heating situation can be expressed as:

$$I_{cons}(HMS) = \frac{E_{cons}}{\eta} \times \begin{bmatrix} f_{pe} \\ f_{em} \end{bmatrix}$$

With :

E_{cons} : net heating requirements over a period equal to the life of the HMS (kWh)

η : efficiency of the heating system

f_{pe} : primary energy conversion factor

f_{em} : emission factor

As the selected dwellings are heated only by gas or electricity, the different factors can be grouped in the following table (table 5).

Table 5. Primary energy and emission factor according to the type of heating (ADEME 2019)

	Gas	Electricity
$\boldsymbol{f_{pe}}$ (kWh_{pe}/kWh)	1	2.58
$\boldsymbol{f_{em}}$($kgCO_{2,eq}$/kWh)	0.227	0.132

3. Impact of the heating management system

The impacts of the heating management system are calculated using life cycle assessment (LCA) results published by the manufacturers on the internet. These impacts represent the investment made in terms of environmental impact $I_{invested}$. Considering the n devices that constitute the HMS, the impacts over the whole life cycle are expressed as follows:

$$I_{invested}(HMS) = \sum_{k=1}^{n} a_k I_k$$

a_k: number of k^th devices constituting the HMS

I_k: impact vector of the k^th device on the whole life cycle

4. Environmental benefits of the heating management system

1. Reference case

In the perspective of comparing heating management systems with each other, it is necessary to define a reference case (RC). Thus, for the application of the methodology, RC is defined as follows:

RC: Room thermostat without manual setpoint change – thermostat bimetal

RC differs from P_1 in its consideration of HMS-HHBS interactions. Thus, the temperature setpoint remains constant independently of the occupancy scenario of the household. In addition, the impacts of the consumption and the impacts of the HMS, in this case, are determined following the methodology figure 1.

2. Comparative analysis

The environmental benefits are determined from a comparative analysis, for a fixed household-housing-behaviour association, between the impacts of RC and those of HMS. Thus, for the expression of the impact vector due to gains:

$$\Delta I_{cons}(HMS) = I_{cons}(RC) - I_{cons}(HMS)$$

As the reference case assumes the presence of a room thermostat with manual setpoint change, the life cycle impacts of the HMS and the reference case should be compared.

$$\Delta I_{invested}(HMS) = I_{invested}(HMS) - I_{invested}(RC)$$

Finally, the environmental benefits (EB) of HMS with respect to RC are equal to:

$$EB = \begin{bmatrix} EB_{pe} \\ EB_{em} \end{bmatrix} = \Delta I_{cons}(HMS) - \Delta I_{invested}(HMS)$$

With:

EB_{pe} : environmental benefits in kWh_{pe}

EB_{em} : environmental benefits in $kgCO_2eq$

IV. Results and discussions

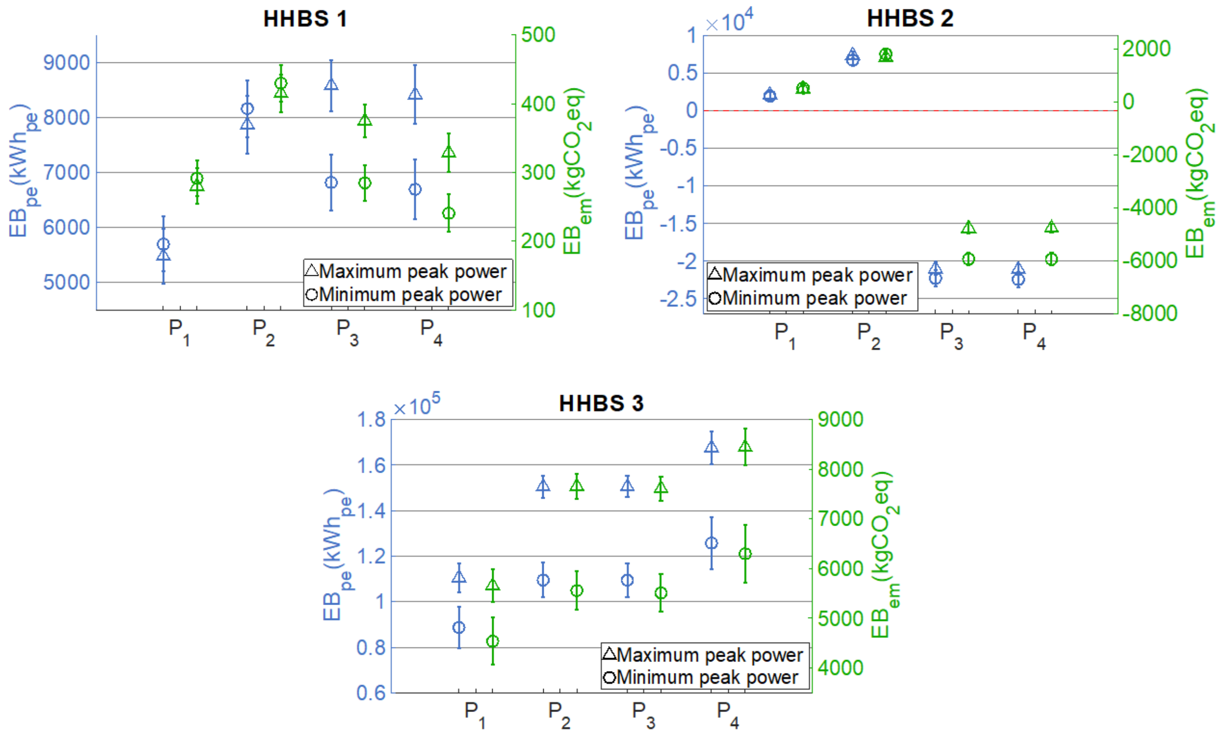
The methodology was applied to each HMS-HHBS combination (12 combinations). Furthermore, as no information on the heating system was available, the conversion efficiency for all simulations is taken to 1. In addition, the results are calculated considering the sensitivity to the installed power capacity. Two cases are considered: A "Maximum Power Peak" scenario (installed power limited to 100 W/m^2) and a "Minimum Power Peak" scenario (power limited to 70 W/m^2 except in the living room where it is limited to 100 W/m^2). For each HHBS-HMS configuration, and each installed power capacity scenario, the heating requirement is simulated 10 times. The average environmental benefits and the associated standard deviation for each HMS for a fixed HHBS are shown in figure 4. The number of devices considered for each combination are specified in annex 3. The results are also summarized in the annex 4.

HHBS 1: The first dwelling is a three-room apartment of 41 m^2 with a living room, a bedroom, and a bathroom. It is occupied by a young couple without children who are often absent but adopt rather energy saving behaviours. In this situation, the implementation of an HMS is always environmentally beneficial according to the two indicators used. The optimum depends on the power scenario. Indeed, in the case of the "minimum peak power" scenario, the optimal management system for primary energy savings is reached with P2 for which the EB_{pe}, for maximum and minimum power scenario, lies between 7.9 MWh_{pe} and 8.2 MWh_{pe} over 10 years, or an average of 20 kWh_{pe}/m^2 per year. For the maximum peak power scenario, the optimal system is P_3. Finally, the observation of P_4 shows that the addition of a sophisticated management system does not have an environmental interest compared to P_3 although it offers better primary energy savings. This can be explained by the economic behavior of the household. Indeed, the more the household tends to turn off the heating during an absence, the less relevant is the addition of a sophisticated management system.

HHBS 2: The second dwelling is a 71 m^2 4-bedroom flat with a single occupant who is retired. The insulation is of poor quality because the dwelling was built before the 1974 thermal regulations. First, the figure 4 shows that the room-by-room temperature controls P_3 (-21 MWh_{pe}, -4.7 tCO_2eq on average over 10 years) and P_4 (-21,1 MWh_{pe}, -4,8 tCO_2eq on average over 10 years) leads to negative impacts while single thermostat regulations like P_1 (2.1 MWh_{pe}, 481 $kgCO_2eq$ on average over 10 years) and P_2 (7.4 MWh_{pe}, 1.7 tCO_2eq on average over 10 years) are environmentally profitable. This result can be explained by the fact that thermal comfort was significantly improved with HMS P_3 and P_4. In the end, moving from one technically more advanced HMS to another does not guarantee the reduction in heating consumption. In addition, due to the poor initial thermal comfort in this HHBS, it is seems difficult to conclude on an optimal management system. To explain these results it can also be said that the high occupancy of the dwelling decreases the interest of adding systems to reduce energy consumption during the absence phases.

HHBS 3: The third dwelling is a 113 m^2 detached house occupied by a middle-income family who has high heating requirements and low regulation behaviours. As the previous dwelling, the thermal envelope is of extremely poor quality (built before 1949). For this type of housing and household, the increased complexity of the control system is interesting. Indeed, we find here a bundle of elements indicating an important source of energy savings: large surface area with little insulation, rather energy-consuming behaviour, low presence in the dwelling. The optimum in terms of both primary energy and emissions savings is reached for P_4 (126-168 MWh_{pe}, 6.3-8.4 $tCO_{2,eq}$ on average over 10 years), which corresponds to a reduction in heating consumption of 130 kWh/m^2 per year. However, it is important to remind that the mere fact of installing a room thermostat with manual setpoint change (P_1) generates already savings of 100 MWh_{pe} and 5 $tCO2_{eq}$ on average over 10 years. However, the reduction in heating requirements (-39%) needs to be considered very carefully in scenario P_4, as this is an extremely poorly insulated house for which there is perfectly synchronised control over the presence of the heating system.

Figure 4. Environmental benefits for the 3 study cases, and the 4 hardware selection strategies (P_i). The strategies are compared according to their environmental benefits over the entire life cycle (10 years). The two EB are the saved primary energy (EBpe) and life cycle greenhouse gas emissions avoided (EBem).



V. Conclusion

In this work, we defined a methodology to compare the environmental benefits associated with the use of heating automation systems. It was applied to three case studies that are representative of French households and housing situations. These have been constructed from classification work on French households and dwellings. To assess the environmental relevance of the control systems, we compared their impacts, calculated from open-source data, and the avoided impacts resulting from heating savings, estimated using dynamic thermal simulation software.

In all cases, it was observed that the increase in complexity of the automation systems does indeed reduce the energy requirement for heating. However, the observation of the impacts shows that the optimal management system depends strongly on the study case and on the choice of impacts indicators. Furthermore, our calculations suggest that the orders of magnitude of environmental benefits for the same equipment strategy differ on average by a factor of 1 to 18 in primary energy and 1 to 10 in greenhouse gas emissions, depending on the household and dwelling considered.

Moreover, this work is still preliminary and the results will have to be consolidated. We see several possible improvements. Firstly, a sensitivity study on the parameters used (insulation level of housing, location) in the simulation should be conducted. In addition, considering solar gains and dynamic models of internal power dissipation would improve the calculation of the environmental benefits. Also, the improvement of the probabilistic models of household presence will be explored by using time-use surveys. Finally, it could be interesting to refine the interaction model between the HMS and the inhabitants.

It is important to underline that the sensitivity of the results to advance heating controls algorithms is not explored in this work. Nevertheless, the work carried out here provides some elements of reflection for the actors involved in housing automation (researchers, manufacturers, public decision-makers). Indeed, our results suggest that the environmental benefits of automation are significantly higher for certain segments of dwellings and households (for example, working households occupying large houses with a low level of insulation).

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Annex 1 : List of parameters of each HHBS used for the simulation

HHBS1

Parameters	Household archetypes [Lévy, 2018]	Housing archetypes (TABULA) [Loga, 2016]	Behavioural archetypes [Heinrich, 2022]
Reference in the original work	ENL7	06-MFH	“Economic house”
Energy used	Electricity		
Type of dwelling	Flat	Flat	
Composition of the household	2 persons		
Area of the dwelling	Urban	Urban	
Surface of the dwelling	<70 m^2		

Layout		X	
Construction period	After 1975	Between 1982 and 1989	
Materials of the Thermal Envelope		Concrete facade + 8 cm PSE	
Windows		Double glazing 4/6/6	
Doors		X*	
Temperature setpoint			Very low
Temperature control			Very high
Presence at the dwelling			Quite absent

* no data on flat doors

HHBS2

Parameters	Household archetypes [Lévy, 2018]	Housing archetypes (TABULA) [Loga, 2016]	Behavioural archetypes [Heinrich, 2022]
Reference in the original work	ENL5	03-AB	"Savings house"
Energy used	Gas		
Type of dwelling	Flat	Flat	
Composition of the household	1 person (retired)		
Area of the dwelling	Urban	Urban	
Surface of the dwelling	4 rooms		
Layout		X	
Construction period	Between 1949 and 1974	Between 1949 and 1967	
Materials of the Thermal Envelope		Concrete wall + render, 20 cm	
Windows		Double glazing 4/12/4	
Doors		/*	
Temperature setpoint			Average
Temperature control			Low
Presence at the dwelling			Very present

HHBS3

Parameters	Household archetypes [Lévy, 2018]	Housing archetypes (TABULA) [Loga, 2016]	Behavioural archetypes [Heinrich, 2022]
Reference in the original work	ENL5	03-SFH	"Leisure house"
Energy used	Electricity		
Type of dwelling	Detached house	Detached house	
Composition of the household	Middle-income families aged 40–59;		
Area of the dwelling	Rural	Rural	
Surface of the dwelling	>100 m^2		
Layout		X	
Construction period	Before 1948	Between 1915 and 1948	
Materials of the Thermal Envelope		Brick wall, 20 cm	

Windows		Double glazing 4/12/4	
Doors		Solid wood door	
Temperature setpoint			Higher than average
Temperature control			Low
Presence at the dwelling			Quite absent

Annex 2 : Environmental impacts of devices

Devices composing the HMS			
Device	**Reference**	**Primary energy used* (kWh$_{pe}$)**	**Global warming* (kgCO$_{2eq}$)**
Bimetal thermostat	Hager EK05	2.54	0.907
Programmable thermostat	Hager 5202	241.7	57.7
Thermostatic valve	Hager EK6	40	8.54
Connected thermostat	LeGrand LG-049036	522	104

* *Source:* pep-ecopassport.org

Annex 3 : Number of devices considered for each combination

	HHBS 1					**HHBS 2**					**HHBS 3**				
HMS	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**
Bimetal thermostat	**1**	1	0	0	0	**1**	1	0	0	0	**1**	1	0	0	0
Programmable Thermostat	0	0	1	1	0	0	0	1	1	0	0	0	1	1	0
Thermostatic valve	0	0	0	3	3	0	0	0	4	4	0	0	0	7	7
Connected thermostat)	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1

Annex 4 : Average energy requirement for heating

The energy requirement is given below for ten years of consumption with a heating equipment limited to 100 W/m^2

	HHBS 1					**HHBS 2**					**HHBS 3**				
HMS	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**
E_{cons} (MWh)	**19.5**	17.3	16.4	16	16	67.3	65.1	59.6	87.8	87.5	328	**285**	**269**	**269**	**262**
ΔE_{cons} (MWh)*	0	2.1	3.1	3.5	3.5	0	2.1	7.6	-20.6	-20.3	0	42.8	58.4	58.5	65.3
EB_{pe} (MWh$_{pe}$)	0	5.5	7.9	8.6	8.4	0	21.1	7.4	-21	-21.1	0	110	150	150	168

EB_{em} (kgCO₂ eq)	0	280	410	380	330	0	481	1672	-4768	-4758	0	5660	7660	7611	8443

***** comparison between $E_{cons}(HMS)$ and $E_{cons}(RC)$

The energy requirement is given here for ten years of consumption with a heating equipment limited to 70 W/m^2 in most of the rooms.

	HHBS 1					HHBS 2					HHBS 3				
HMS	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**	**RC**	**P_1**	**P_2**	**P_3**	**P_4**
E_{cons} (MWh)	19.5	17.3	16.2	16.7	16.7	61	59	54.3	83.2	83.3	281	239	223	223	216
ΔE_{cons} (MWh)*	0	2.2	3.3	2.8	2.9	0	1.9	6.7	-22.3	-22.4	0	42.9	58.4	58.5	65.3
EB_{pe} (MWh_{pe})	0	5.8	8.2	6.8	6.7	0	1.9	6.7	-22.3	-22.4	0	89	110	109	126
EB_{em} ($kgCO_2eq$)	0	291	429	284	240	0	517	1799	-5931	-5939	0	4540	5559	5511	6299

***** comparison between $E_{cons}(HMS)$ and $E_{cons}(RC)$

Market transformation for Heating & Cooling equipment in Europe: using benchmark and advice to involve stakeholders

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Abstract

Space heating and water heating consume over 5'000 TWh/a, nearly 50% of the primary energy consumption of the EU and more than 50% of greenhouse gas emissions in CO_2eq. (in 2015). Space cooling equipment rates grew in the last years, due to climate conditions and comfort requests. The most beneficial action to take is first to insulate buildings to reduce energy needs and improve comfort and air quality. While not all households can retrofit their house, many are anyway in a situation of either investing in a new system or developing low-cost strategies to improve their comfort. The H2020 project "HACKS – Heating and Cooling Knowhow and Solutions" works on both these axes: 1) For all consumers, especially those who cannot invest in a new system, it provides advice on how to improve comfort and air quality and lower energy bills. 2) For consumers ready to invest, it provides tools enabling them to make informed decisions such as benchmarks and lists of most energy efficient products elaborated thanks to continuous market studies. For example, once the decision is taken to invest e.g. in a heat pump system, all other things being equal, there are large performance differences between products on the market.

In order to achieve a fast market transformation, all relevant stakeholders need to be involved: not only manufacturers and consumers but also installer networks, retailers, consumer organisations and governmental policies such as rebate programmes. The paper discusses different strategies to connect those stakeholders, within the HACKS project which is implemented in 15 countries in Europe. It presents a broad overview of different strategies, environments and levels of success. Best practice examples are highlighted as well as the tools developed by the project: papers for each technology presenting the key points to watch, a product database showing market evolutions, a calculator, a catalogue of advice, communication campaigns.

The Topten approach and its adaptation for heating and cooling appliances

This paper presents the activities and first results of the HACKS project (09/2019-08/2022) – Heating and Cooling Knowhow and Solutions[238] – funded by the European research programme Horizon 2020. HACKS gathers 17 participating organisations from 15 countries, most of whom have been working together for the last 15 years within the "Topten" movement. Topten's goal is to mitigate climate change and contribute to environmental protection, by transforming the market towards more energy efficient products. Since the differences between electrical appliances regarding their energy efficiency is still significant even when they provide a same level of service, a careful selection of these goods is key for a sustainable market transformation. Topten facilitates this selection process by providing, on its websites in free access, the latest market information on products to the benefit of consumers, producers and policy makers.

Working within a European network allows benefiting from synergies – when facing global technology developments or international manufacturers - while at the same time presenting market information tailored to the specific needs and context of local consumers.

Topten's main activities are the following:

- Identification and display of most energy efficient products: Products are selected and ranked based on sound market research and impartial evaluation considering criteria specific to the respective national markets.

238 For information on the HACKS project and its participants, see https://www.topten.eu/private/page/hacks. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 845231. The sole responsibility for this content lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the EASME nor the European Commission are responsible for any use that may be made of the information contained therein.

- Policy advice: By showing the most energy efficient products on the market, Topten provides information on the Best Available Technology (BAT). With this evidence on the BAT, its technical know-how, and its policy recommendations, Topten supports the European Commission and other policy stakeholders in designing effective policy measures, such as minimum energy performance standards and energy efficiency labelling.

- Communication and dissemination: Topten cooperates with the media and other multipliers, such as environmental and consumer NGOs, which relay the Topten message as part of their work. Furthermore, Topten undertakes different communication activities targeting end-consumers.

- Cooperation with public procurers and retailers: Topten provides advice to public procurers, including the development of concrete procurement tools, such as templates for tender documents for example. It furthermore maintains a dialogue with the manufacturing industry of consumer goods, especially on upcoming technological innovations, focusing on the demand and interest for energy saving products. Moreover, Topten cooperates with large public and private buyers, including retailers, who make energy savings one of their priorities.

The start of the HACKS project marks a turning point in the Topten approach. While Topten had been working mostly on plug-in domestic appliances since 2000, focusing on heating and cooling appliances opens new dimensions because these are much more complex products which "interact" with the building's envelope:

- The energy consumption of heating and cooling appliances depends very much on their correct dimensioning: a super-efficient but oversized boiler may consume more than a poor performing smaller model. Hence providing advice only on product's performance is insufficient.

- Consumers hardly ever choose themselves the model that will be installed in their home: they (rightly) rely on specialised installers – who form a difficult target to reach when proposing information, training, possible change of suppliers, etc.

- The most beneficial action to take is first to insulate tight and ventilate right the buildings, in order to reduce energy needs and improve comfort as well as air quality by eliminating combustion particles and suppressing mould forming. From an individual perspective (potential savings) as from a collective perspective (fight against climate change), this has to be communicated before providing advice on solely changing a boiler – which presents lower potential benefits – even if home insulation is a much bigger challenge and is not an obvious topic when the old boiler breaks down and has to be replaced.

However, whether households retrofit their house or not, they can invest in a new system or develop low-cost strategies to improve their comfort. Hence, HACKS works on both these axes: Firstly, for all consumers, especially for those who do not want to or cannot invest in a new system, it recommends strategies on how to improve comfort and air quality and lower energy bills with the existing system. Secondly, for consumers ready to invest, thanks to continuous market studies, it provides lists of most energy efficient products (benchmarks), enabling them to make informed decisions. For example, once the decision is taken to invest e.g. in a heat pump system, all other things being equal, there are large performance differences between products on the market (lifetime costs can increase twofold for this product group between products selected for their efficiency and least efficient models allowed on the market).

The HACKS project main activities

Heating and cooling: the need for action

Space heating and water heating consume over 5,000 TWh/a, nearly 50% of the primary energy consumption of the EU and more than 50% of greenhouse gas emissions in CO2eq. Space cooling equipment rates grew in the last years, due to climate conditions and comfort requests. Heating and Cooling (HAC) equipment are clearly an energy stake for the EU, especially since almost half of all buildings have individual boilers installed before 1992, with efficiency of 60% or less. For over 22% of individual gas boilers, 34% of direct electric heaters, 47% of oil boilers and 58% of coal boilers, the intended technical lifetime has been surpassed [1].

However, consumers in most cases are unaware that their HAC equipment is outdated and that it needs to be replaced (and even if they are aware, the typical attitude for such non visible appliances is for many people to replace only when it breaks). They are also unaware that the economic benefits and their monetization (cost saving, payback periods, demand response) and environmental benefits (improved air quality through a reduction of GHG and fine particles emissions, increased comfort) can be very positive in the long-run and permanently reduce consumption. Moreover, consumers are confused by the manifold information available on HAC equipment and alternative solutions. Since for the greater part they are not specialists in the topic, they can get easily overwhelmed by the terminology used in the sector and may feel helpless. In recent years, several Energy Labels have been introduced - simplifying the interpretation of product performance for consumers. However, these also remain rather complex to understand for a consumer with little technical knowledge. In addition, in the HAC sector, consumers depend heavily on third-parties (i.e., installers, retailers) for the selection, purchase and installation of new equipment. If an installer recommends a HAC product, it is very unlikely that consumers will challenge the general recommendation.

This situation, which was anticipated before the HACKS's activities started, was further studied in a so-called "HACKS base line report" [2] in which each of the national HACKS teams mapped-out an overview for their country:

- The state of the art of heating and cooling technologies, policies and markets: specific national or local regulation for HAC equipment (country-specific minimum performance standards or requirements, mandatory information), or possible national voluntary schemes or labels and support schemes such as rebates, tax incentives, replacement programmes, and energy savings obligations.

- The existing stock and installed technologies, the expected savings per units in given conditions, the expected comfort and health improvements, assessing the HAC practices for the different climatic regions, identifying the most appropriate technologies for each context; and looking for innovative and original solutions that can reduce or offset the use of some HAC equipment.

- The market characteristics for HAC goods and services. It provides a detailed insight on the market mechanisms and structures, the key actors, the market patterns. Understanding the market structure for HAC products contributes to identifying the levers that HACKS participants must address to better reach consumers and motivate them to replace their inefficient HAC equipment.

This assessment helped to set national priorities and identify which systems are predominant in each country, what products should be replaced first; which products and solutions should be pushed to maximise energy savings and improve quality of life; and how to best motivate consumers (directly and indirectly). Thus, it guided the HACKS activities implemented at the national level and described below.

Advice for low or no-cost energy savings

HACKS focuses on installed heating and cooling appliances that represent the most energy consuming appliances in households with the goal to replace existing equipment that has reached its technical lifetime or that is a candidate for an early replacement (see section below). However, as many households cannot change their equipment e.g., because of financial limitations or because they just rent their home, HACKS also includes in its analysis alternative solutions such as complementary products. Such measures, targeting more energy sufficiency than efficiency, can immediately lower the use or the energy consumption of the more complex main equipment. Examples are comfort fans, sun blinds and shading systems (instead of ACs), or equipment to reduce the energy consumption by reducing the output (saving taps and shower heads consuming less hot water) or optimize the energy consumption (thermostats). The project has produced a so-called "HACKS Catalogue of Key Information Topics" [3][239] that serves as a basis for national participants: they can find inspiration and adapt the topics to their national situations. After introducing the concepts of comfort and air quality, the catalogue provides:

- Solutions for reducing the use of heating and cooling equipment while improving comfort and air quality, presenting for heating, hot water production and cooling:
    - contextual information: climate change, money savings, multiple benefits of the proposed solutions, examples of arguments to convince citizens that, whenever it can be, heating, hot water and cooling, should be reduced.

[239] This catalogue will be further enriched and updated at the end of the project (summer 2022).

- solutions relating to the equipment itself: e.g., limiting consumption by insulating pipes, using thermostat and programmers, acting against limescale in water heaters; and
- solutions relating to users' behaviour: e.g., adopting good habits with windows (opening/closing/shading) and temperature settings (appropriate to the room, the time of the day), tackling water leaks.

- Advice for choosing highly efficient HAC equipment for a variety of heating and cooling systems: e.g., pros and cons of available technologies, choosing transmitters, tips for correct sizing of the equipment
- Advice for using HAC equipment in an efficient way: e.g., maintain a convenient ambient temperature, check the tightness of the refrigeration circuit, use eco-labelled wood pellets, logs or chips.

Each of the 15 national participating internet platforms thus presents extended advice sections not only on how to choose efficient products but also, generic principles on how to size products and how to use them in order to save energy, or how to e.g., avoid the use of cooling appliances while adapting indoor comfort by using sun blinds on the windows according to their orientation at the right moment of the day, using fans and ventilators, or natural ventilation especially at night, etc. For example, the landing page for cooling advice on the French internet platform[240] offers several sections: Cooling and climate, Alternatives to air conditioners, How to best use air conditioners to consume less energy, Install and maintain an air conditioner, and for those who can invest How to choose an air conditioner.

Investing in new equipment: targeting the best performance

HAC products cause a high energy consumption, so information on the energy consumption, costs, environmental aspects and identification of Best Available Technologies (BAT) is very useful. By displaying lists of BAT products and setting the benchmark, HACKS uses a pragmatic approach and promotes best products and best practices while remaining independent of commercial interests of market actors (suppliers do not register their products, which get selected by Topten).

The objective is to participate in filling the information gap exposed above: the 15 HACKS dedicated websites provide precisely tailored information on the available solutions, organised by product categories (e.g. heat pumps, solid fuel boilers) providing consumers in a credible manner with clear recommendations on how to choose energy-efficient products, how to interpret the energy label, and with lists of super energy efficient models for each category online. Providing this comprehensive information aims at unlocking the full potential of multiple benefits of energy efficiency improvements. These multiple benefits can be a higher thermal comfort, a better indoor air quality, a reduction of environmental impact, an improvement of aesthetics, of the controls for the users, an added value for the property.

To reach these results and identify the BAT products (of which an example is provided in Figure 1), the project first developed so-called "Criteria papers" [4] for eight product groups, i.e., detailed research on air conditioners, circulation pumps, comfort fans, local space heaters, solid fuel boilers, space heaters, water saving taps and shower heads and water heaters. The primary objective of these "Criteria papers" is to help HACKS participants to develop knowledge on new product categories (as most participants do not rely on own engineers for the HACKS works), but the technical content may also support any interested person willing to find good products from an environmental point of view. Each paper is between 15 and 20 page-long and presents:

- an overview of the product's role in buildings
- the current EU regulations that apply for the product category, the expected impacts of those regulations, and the tools they provide to identify best products: energy labels and mandatory declarations in product fiches (e.g., power levels, type of refrigerant)
- proposed selection criteria for best products (those used by the European platform www.topten.eu)
- a brief technical overview is given (and more detailed technical input in annex)

[240] https://www.guidetopten.fr/grand-public/adviser/recommandations-et-conseils-sur-les-climatiseurs

- the list of product characteristics that will be relevant for consumers
- recommendations on how to find the data for this product category through market research
- additional information in the form of useful links, a glossary and a FAQ section gathering important topics for consumers

Each national participant then performs market research for its country, assesses the selection criteria for the most efficient models available on their local market (since the product offer is not homogeneous across Europe), double-checks on paper the energy efficiency indexes that can be recalculated from the products' declarations, and displays those criteria and the corresponding product list on their website (Table 1).

Table 1. Overview of the different HAC product categories displayed on the national platforms participating in the HACKS project (as of 01/2022)

Equipment	AT	BE	CZ	FR	DE	IT	LU	PL	PT	ES	NO	LT	SE	UK	CH
Ventilators / Fans		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
Air conditioners	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓			✓
Intelligent thermostats															✓
Heat pumps	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Solid fuel boilers	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wood Pellets							✓	✓							✓
Local space heaters	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Heat pump water heaters	✓	✓	✓			✓	✓	✓	✓					✓	✓
Electric water heaters, combined water heaters	✓											✓			
Electric showers														✓	
Dehumidifiers															✓
Humidifiers			✓												✓
Taps and shower heads		✓	✓	✓	✓	✓		✓	✓	✓				✓	✓
Circulation pumps		✓	✓			✓	✓	✓			✓	✓	✓		✓
Windows								✓					✓		✓
Insulation materials	✓						✓								
Doors								✓							
District heating													✓		
Solar Thermal collectors								✓							

Participants adapt selection criteria to their national market, from the consumers' perspective – e.g. if there exist national labels to rely on, if there are a lot of small manufacturers to review, if the offer is not very good from the energy point of view, etc. For example, to select the heat pumps displayed in France, the HACKS partner used the criteria paper on heat pumps, cross-checked and merged product information from three sources (Topten.eu, Eurovent and EHPA databases), did a lot of internet research to complement the information and assess national availability of products, before deciding to base its selection criteria in terms of energy efficiency index. Different levels were chosen for the low temperature models (suitable for floor heating) and the high temperature models (suitable when using radiators) because the market research showed that there is no correlation between the two indices (a model can be super-efficient when used at 35°C but not particularly efficient when used at 55°C or vice versa). The precise levels of efficiency were set so that the product list would not be too long (selecting the really most efficient models) but would at the same time cover different brands and if possible, price ranges. As an illustration, for the air to water products, 774 models from 63 brands are offered on the French market. After elimination of duplicates and products lacking information, etc. the list was reduced to 577 models from 56 brands. Setting the selection criteria at eta_LT<195 (i.e. energy efficiency for the low temperature models) reduced the list to 60 models from 21 brands (it would have been 104 products with eta_LT<185), which after further verification on their effective availability went down to 40 models from 16 brands.

Figure 1 shows an example of how the product lists are displayed for the most energy efficient heat pumps models available on the Swiss market. Visitors can filter products, change the sorting order and click on product to see its full detailed information and a link to the manufacturer's website. The objective is to guide consumers in the hundreds of products available (as they cannot individually undertake the market studies carried out by the HACKS teams), select only the most efficient ones but provide enough choice (for example by not limiting the selection to only one brand).

The HACKS criteria papers and the European platform www.topten.eu focus on benchmarks at the European level and evolution of products from a technical point of view. Figure 2 shows an example in which the Topten selection criteria for heat pump water heaters were tightened in May 2021. Heat pump water heaters are covered by an energy label where the class thresholds are based on the efficiency index η. On Topten, the selection criteria are also based on this label and the efficiency index η. Even though both the energy class and the declaration of efficiency index η have been mandatory since 2018, only few products display this value online; in online research done in 2020 as part of the HACKs project only approximately 7% of products visible online contain both of these data points. Therefore, the majority of product data for the HACKS list has been obtained via surveys directly from the manufacturers. The Topten selection criteria were tightened in May 2021 to allow only water heaters with efficiency class A+ (as opposed to Class A before). While the number of A+ models on Topten.eu have increased, no A++ and A+++ models have been found on the market. It seems that manufacturers have not yet been able to develop sufficiently efficient technologies to reach such classes.

Manufacturers do not have influence on the Topten selection criteria but they are generally contacted:

- to complement desk research data on products' characteristics,
- in case of doubt on a product performance, e.g., if the energy class calculated by Topten is not the same as the one declared by the manufacturer. If no answer is provided or if the doubt persists, the product is not displayed on-line by Topten and may be signalled to national market surveillance authorities,
- when the selection depends on product information manufacturers are not obliged to publish. Though it is difficult and takes time, the Topten experience shows that it is possible to ask also for such information (e.g. an energy consumption according to a specific standard): at first, only front runner manufacturers accept to communicate and their products may be the only ones displayed, until their competitors want their products displayed as well, until it becomes an information that almost all manufacturers reaching a certain level of efficiency want to communicate because they want to be seen on the Topten websites. This incentive process can also support the data gathering and development of regulations at the European level (as seen in the case of professional cold products [5].

Figure 1. Example for the Swiss HACKS platform: www.topten.ch

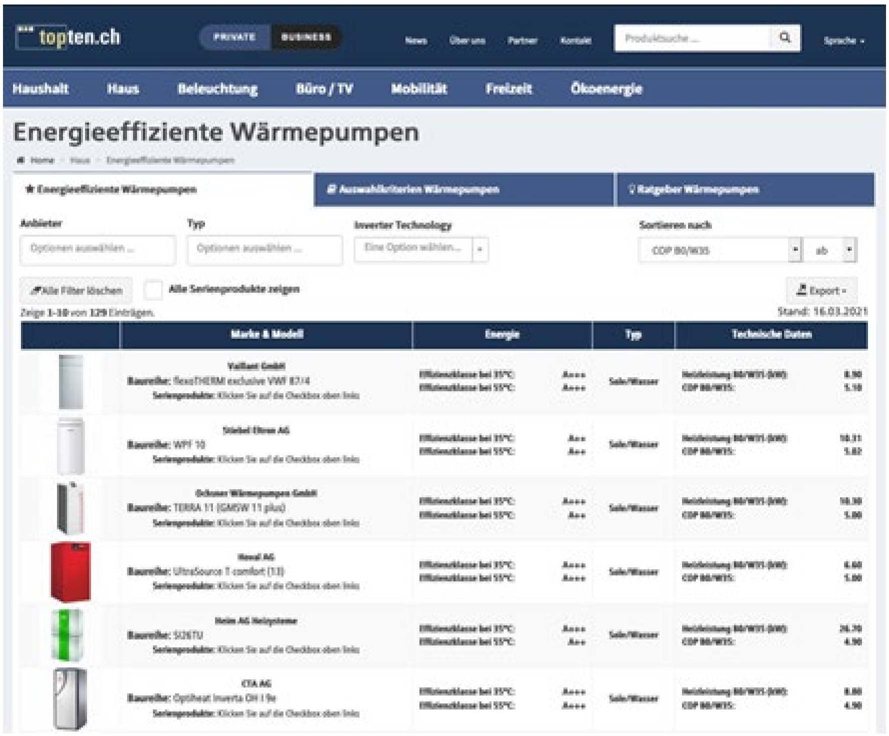


Figure 2. Evolution of the number of BAT products numbers for heat pump water heaters listed on Topten.eu in August 2020 and August 2021

Efficiency Class	2020	2021
A+	34	42
A	3	
Total	**37**	**42**

Source: Topten.eu

Topten Tools: Policy recommendations and HACKS heating simplified calculator

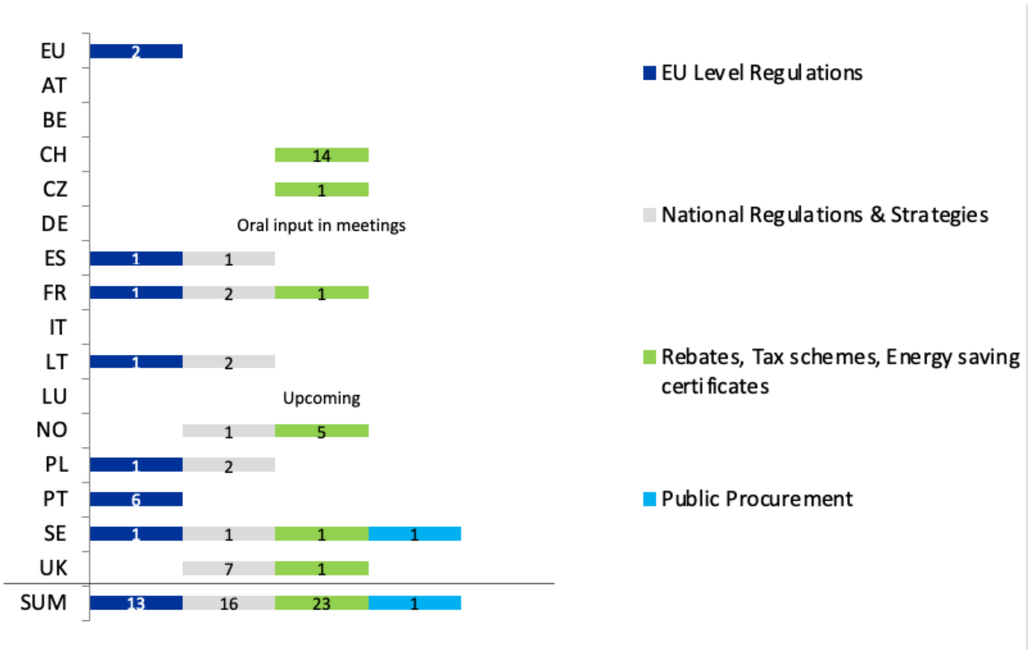
Beyond the BAT product lists and the advice sections, HACKS participants work on two additional tools that combine efficiency and sufficiency aspects.

Policy recommendations

Since the start of the project, the HACKS participants have developed a number of policy recommendations for different types of appliances. While the SARS-CoV-2 pandemic was the predominant topic in all countries during large parts of the project implementation period, many governments are still rapidly progressing in compiling climate strategies and / or subsidy programmes to boost the economies and for a green recovery. Most participants were able provide relevant policy makers with input on best available HAC technologies, efficiency criteria and ways of integrating this input into upcoming regulations and projects. Before the pandemic hit, in total 53 policy recommendations were submitted between September 2019 and February 2020 for the following four levels of policy instruments (see Figure 3):

- EU level Regulations
- National regulations and strategies
- Financial tools: rebates, tax schemes, energy saving certificates
- Public procurement

Figure 3. Distribution of the 53 HACKS policy recommendations developed between September 2019 and February 2020



In order to provide decision makers with even more complete input, HACKS participants worked with other environmental and civil organisations and expanded their policy recommendations to include aspects of fair financing and energy poverty, greenhouse gas and particle emissions (air pollution), energy grid development and necessary training of installers. Participation in NGO communications campaigns on European levels was successful in raising awareness not only with policy makers but also the general public (e.g. campaigns from the technical green non-governmental organisation ECOS on air cooling[241]).

Significant progress and momentum in policy development is scheduled for the second half of the project, especially with regards to the coming review of the energy labelling and Ecodesign regulations for heating and cooling appliances.

241 https://www.coolproducts.eu/uncategorized/this-summer-heatwave-goodbye-to-portable-air-conditioners/

HACKS's simplified heating calculator

In order to help consumers and their installers to get a first generic assessment of their current heating system and compare their performance with alternative new systems, the project has developed a simplified calculator[242] (for now it concerns heating but a second tool targeting cooling is under development).

Visitors can:

- enter simple personal data on their homes (dwelling area, climate zone, number of inhabitants, current heating system, production of sanitary hot water, etc.)
- select alternative heating systems (more efficient)
- select possible home insulation measures (reduce the energy demand)
- and compare the results in terms of energy needs, energy consumption, costs and CO_2 emissions.

Though the calculator's framework is generic (based on average numbers at the European level), it contains a lot of parameters that are customised for each country. The calculator shows that insulation measures are often more beneficial than changing only the heating system, but also allows comparing average running costs and CO_2 emissions of alternative heating solutions.

HACKS' challenge: dissemination

The HACKS project has produced a lot of content and continuously updates its product lists. It is a challenge to actively transform the market, and even more so at a time of global pandemic, which has focused the public's and the media's attention. All HACKs participants have developed – and adapted – national dissemination plans with two main axes: direct communication towards consumers and partnerships with stakeholders who multiply the HACKS messages towards their own networks and target groups.

Targeting the media and consumers

As all projects supported by H2020, HACKS has set itself goals in terms of dissemination and two specific reports (February 2021) present the participants' activities during the first half of the project with this regard to media outreach [6] and consumer involvement [7].

Media outreach

The HACKS participants have each elaborated a marketing plan to promote the content available on their national HACKS online platform. These are often hosted on existing Topten platforms to benefit from existing awareness and traffic. All marketing plans include a strategy on media outreach, covering online and offline publications across partner countries, informing consumers about the HACKS campaign.

Collectively, participants should reach 20 million media contacts (listeners, readers and viewers) in the final year of the project (September 2021 – August 2022). Most participants will calculate at the end of the project the equivalent economic value of unpaid coverage received in journals, magazines, newspapers and websites, with the objective of reaching a media coverage worth half a million Euro. As of March 2021 (latest aggregated overview), in a context that saw many HACKS activities delayed because of the Covid pandemic, 7.65 million people have been reached with information on HACKS. This number is assumed to be under-estimated as for some participants it covers only the social medial reach and not yet the online and print press reach.

The target is to reach collectively between 900,000 and 1,750,000 page views in the last year of the project. As of end of March 2021, HACKS-related content on partner websites had reached over a million page views since the beginning of the project (in September 2019).

The activities undertaken are of various types: preparing short TV transmissions, a video for the WWF YouTube channels, press releases, newsletters, the use of Twitter, Facebook, Linked-in, Whatsapp message feeds and other social networks and news channels.

242 English version: https://calculator.topten.eu/?country=uk

Consumer involvement campaigns

The consumer campaigns use online and offline media activities to involve citizens, raise their awareness about the benefits of efficient heating and cooling equipment and motivate them to replace their old and inefficient heating and cooling equipment.

Once the product lists and advice pages are displayed on the respective internet platforms, national teams continuously work to increase their visibility (e.g., through specific pages, Search Engine Optimisation activities, keywords campaigns, infographics and comic books) and visitor interaction (online contact forms, FAQ sections).

Depending on countries, they provide as many services as possible to visitors, such as:

- "Deep links" allowing visitors to click on a specific product of his / her interest to see where it is sold and possibly buy it (in 5 countries). This service is at an experimental stage at the moment, and concerns a limited number of product categories because the HAC products are most often sold by installers not using deep links. For the more standardised products such as ventilators/fans, when online retailers are too numerous to feature on the HACKS platform, their selection is based on retailer's willingness to provide information through links. Alternatively, the HACKS participants try to link to comparison sites to provide the widest possible choice to visitors.

- Raffles and competition (14,000 consumers have participated in a HACKS raffle in four countries and the European competition).

- Information on rebates for HAC products where available from government and utilities (in five countries).

- Links to certified installers (in four countries)

- Cooperation with consumer organisations (in six countries).

Working with multipliers

The success of HACKS in achieving market transformation for heating and cooling appliances lies deeply on the participation of several key stakeholders - called "multipliers" because they relay the HACKS' messages to their own target groups. Their wide variety of expertise, networks, communication channels and connections with consumers contributes to the development of different and important activities together with the partners.

Multiplier capabilities and expectations differ and require different approaches, collaboration methods and tools, which participants have to take into consideration.

- Retailers and installers are key actors for this project as they make the direct link between HAC products manufacturers and consumers. Their influence on both is very relevant and crucial for the project, but the technical way to engage and cooperate with each one is very distinct and challenging; especially installers.

- National authorities and decision makers are responsible for the design of policies and financial mechanisms, so their involvement is important/.

- Environmental and civil organisations support consumers decision making and have direct contact with target groups. Their contact networks are usually very broad and organised and additionally they often have well-established projects, campaigns and communication channels where these issues can easily be integrated.

- Utilities and housing associations are focused on their brand reinforcement and on their clients' satisfaction. Participation in projects like HACKS is appreciated because it is good for their image on the market. Moreover, utilities often have legal obligations regarding energy efficiency measures.

- Universities and research centres can provide the technical knowledge essential for the development of project specific content and activities and for the collaboration with some stakeholders. They benefit from the access to updated market data.

- Professional and trade associations, though generally not energy efficiency-oriented, may profit from the project's simple language and overall reach, to promote their expertise. They represent a good starting point to contact and engage retailers and installers (and manufacturers who are often contacted when preparing the BAT product lists).

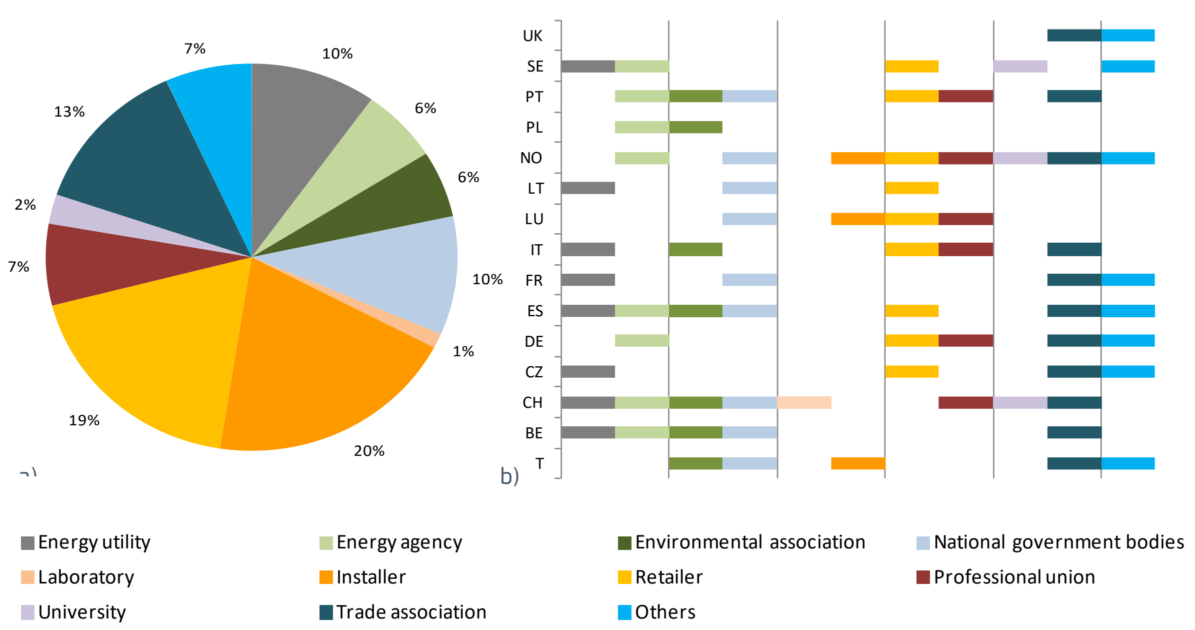
- Professional (private and public) procurement can profit from detailed specifications and tailored information to be used in their calls for tenders in order to reduce their operating costs. Green procurement is gaining momentum although at a low pace, as price is still the prevalent factor in decision-making. Examples of efficient and cost-effective equipment are important drivers for market transformation. HACKS Procurement guidelines are available on the European platform[243].

Since the beginning of the project, all participants have developed activities with multipliers and engaged with new ones. However, pandemic lockdowns six months after the beginning of the HACKS project had a huge impact on of the planned activities: most public meetings, events and face-to-face contact campaigns were put on hold, and could not be fully compensated by new approaches like video conferences.

Nevertheless, building on existing Topten arrangements, participants managed to establish 162 partnerships (Figure 4). A detailed analysis of these partnerships is presented in the HACKS report on the Multipliers' involvement campaign [8]. HACKS partnerships include:

- A utility or a local government using the BAT product lists as a basis for rebate programmes
- Co-organisation of workshops on energy poverty
- Energy advisers being informed of the HACKS services
- Participation in European wide campaigns organised by environmental NGOs
- Technical input for policies on building renovation
- Working with installer and retailer networks
- Research projects on BAT products

Figure 4. Distribution of the 162 HACKS partnerships with multipliers (August 2021)



[243] www.topten.eu/pro

Project Evaluation, conclusions and outlook

HACKS, while implementing the Topten approach, covers a wide range of activities, from detailed market and technical studies to dissemination to various target groups including the general public. This versatility offers many different types of indicators for evaluation.

The outcomes may include: a city modifies its procurement policy; a utility decides on a rebate programme; policy makers favour ambitious regulations; NGOs communicate on energy savings in homes in order to link individual behaviour and climate change issues; retailers choose to adopt energy efficient positioning and revise their product range; installers dedicate more time and attention to best practices; manufacturers develop new efficient models and strongly market them; consumers' demand for efficient models grow – Though these decisions depend on the strategies stakeholders decide to adopt, HACKS may weigh, more or less explicitly, in all of these decisions transforming markets.

The Topten approach has been carried out at the European level since 2006, in up to 18 countries, covering progressively more product categories. It has been evaluated roughly every three years within given projects funded by the European Union. The last available evaluation carried out by the Oeko Institute [9] concluded, for a 42 months project implemented in 16 countries, the following cumulated lifetime savings of products purchased due to the Topten websites:

- electricity savings of over 1,000 GWh
- electricity costs reduction of 216 million Euros
- and reduction of GHG emissions of 607,000 t CO_2 eq

This evaluation was based on a visitors' survey on super-efficient products' purchases. Additional indicators were taken into account such as collaboration with retailers further promoting BAT models, the organisation of product competitions stimulating product efficiency improvement and collaboration with professional procurers which purchasing power influence the market development.

Although several teams used their Topten knowledge to produce policy recommendations for EU Ecodesign and Energy Label regulations, these recommendations were not included in the calculations of the project impact. However, an external study, conducted 2015 by a renowned evaluation specialist on behalf of the WWF [10] has shown that the impacts of the Topten policy recommendations exceed by far the other types of impacts. One example of Topten's successful intervention in the policy making process at EU-level is the tightening of the A+++ class for air conditioners by about 10%. Thanks to its market analysis and testing of products according to the new standard, Topten revealed that appliances on the market were already fulfilling the first planned A+++ class requirements before the enforcement of the new label in 2011.

In the framework of the HACKS project, the funding programme Horizon 2020 asked for an evaluation in terms of saved GWh and involved consumers. A methodology has been developed and accepted by the EASME (European Agency for Small and Medium Enterprises, which manages H2020) to assess these as best as possible considering the fact that, within the market transformation tool box, HACKS/Topten is considered as a "soft measure" in the sense that it provides factual information and link it to positive outcome (energy demand reduction thanks to the transformation of the demand and of the supply sides of the market) – as opposed to "hard measures" (such as investments in R&D leading to a higher machine's output) which impacts are easier to quantify.

A series of indicators is monitored and will be used to evaluate the savings and related avoided CO_2 emissions or to convert into "involved consumers". This evaluation is planned for the last year of the project when the new HAC product categories will have been fully developed (September 2021 – August 2022). A first evaluation at least on the savings was done at the midterm of the project covering the period September 2019 – March 2021 [11].

The HACKS evaluation methodology assumes that the relative contribution of different activities to the overall outcome is as follows:

- Pages views on the HACKS platforms for 40% of the impact. A certain share of the page views lead to expected actions taken by consumers, which allows the calculation of saved kWh based on assumptions concerning the actions, the products, their lifetime, energy consumption and expected savings. The consortium performed an analysis of the EU stock, EU sales and energy efficiency benchmarks for each product group to project product improvement based on research from the EU preparatory studies, knowledge on technologies, and the participants' experience with HAC equipment[244]. For each product group, a number of page views is estimated as necessary to consider that one consumer realises the projected savings.

- Media contacts (defined as when a reader, a listener or a viewer has been in contact with the project such as through a published article, or e.g. as part of a television programme) for 15% of the impact. Here also, based on expert judgement, a number of media contacts is estimated as necessary to consider that one consumer realises the projected savings.

- Partnerships with stakeholders (installers, retailers, consumer organisations, other multipliers) for 30% of the impact. A conservative assumption of 600,000 saved kWh over the cumulated product's lifetime was assigned to each partnership (for example if a partnership is concluded with a retailer improving its range of fixed ACs and training its salespersons in the use of the HACKS calculator).

- Actions targeting manufacturers for 15% of the impact. The assumption of expected savings per manufacturer involved as the effect of the project duration is also set at a relatively conservative hypothesis (1 GWh in average over the cumulated product's lifetime). The Topten platform's experience shows that displaying energy information for specific products – i.e. bringing transparency to the market – stimulates manufacturers; many of them make a lot of efforts to improve their product's efficiency and performances (including changing their product lines) to be able to feature their products online.

The four above indicators were monitored during the first half of the project (until end of March 2021) in the participating countries, (i.e., not yet at the project's cruising speed, and sometimes still with missing information) resulting in savings of 245.4 GWh final energy and providing evidence that the HACKS project is on track to deliver the expected savings by the end of the project.

In addition to this quantitative encouraging preliminary evaluation, it is interesting to note that the Topten approach seems to also fit less standardised products that it usually works on: there are very large energy performance differences between products on the market. It is important to underline those differences, even if for a heating or a cooling system it is also crucial to work on the building's envelope with which the system interacts, in order to first reduce the energy needs for the heating and cooling services, before identifying which technology and which model is best suited. The challenge for the second part of the project will be to convince installers and retailers to use the HACKS inputs to change their daily practices and provide their client with arguments to choose the most efficient products and solutions.

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6 BUILDING

Energy Performance Certificate registers as a policy tool to monitor the Italian Technical Building System stock and evaluate the application of the energy regulation framework

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Abstract

The performance of Technical Building Systems (TBSs), along with building envelope and Renewable Energy Sources (RESs), is important in reducing building energy consumption and greenhouse gas emissions. For this reason, the monitoring of existing TBSs is crucial for identifying suitable energy policies and adopting building renovation strategies. In this context, Energy Performance Certificates (EPCs) are an important data source on building thermal and geometrical characteristics and final energy uses. The management of EPC data allows a combined analysis of different parameters to evaluate the existing building and TBS stocks. The Italian EPC digital register, the Informative System on EPCs (SIAPE in Italian), collects and organizes the EPCs transmitted by Regions and Autonomous Provinces. In this study, EPCs issued from 2015 to 2021 were analyzed to evaluate TBS characteristics on the Italian territory by combining them with other building information, such as the construction period or the purpose for EPC issuing. In this way, the mapping and the investigation of the existing TBSs on the Italian territory can be analyzed, as well as the influence of the energy regulatory framework and the energy system evolution in specific building categories. According to the Italian energy regulations, the analyses focused on the residential sector and its main final energy uses (space heating (SH) and domestic hot water (DHW)). The paper aims to introduce SIAPE and EPC register as tools for describing the TBS stock, providing useful information for policymakers to define and monitor building renovation strategies.

Keywords

Energy Performance Certificates, EPC digital register, SIAPE, Technical Building Systems

Introduction

As requested by the Energy Performance of Buildings Directive (EPBD) 2018/844/EU, each Member State (MS) must establish a Long-Term Renovation Strategy to support and promote the building stock energy renovation and its path to decarbonization. The European building stock is old, and more than half of it is equipped with inefficient boilers (less than 60%) [1]. Furthermore, Heating, Ventilation, and Air-Conditioning (HVAC) systems installed in European Union's (EU) buildings are responsible for more than half of their consumption [2]. In this context, the efficiency of Technical Building Systems (TBSs) is crucial to reaching the EU's targets. At the European level, the residential sector is responsible for about 26% of total energy consumption [3]. Space Heating (SH) and Domestic Hot Water (DHW) TBSs account for the highest energy consumption among the residential energy needs [4], [5]. The heating need is responsible for the 78% of energy consumption in dwellings due to SH (68%) and DHW (15%) [6]. Renewables account for 28% of the SH consumption and about 13% of DHW production. Artificial lighting consumes about 15%, and cooking and other uses about 7% [6]. Energy consumption for space cooling is responsible for only 0.4% of total consumption. In terms of energy carriers, the most used one is natural gas (about 32%), while electricity is about 25%, renewable and wastes 19.5%, and derived heat about 9%; finally, liquid and solid fossil fuels represent about 15% of the residential consumption. Eurostat [6] also provides information on energy consumption by energy carriers and final energy uses, showing that electricity is mostly used for lighting, space cooling, and other needs. Natural gas accounts for about 30%-40% of the SH, DHW, and cooking needs.

The Directive 2010/31/EU sets mandatory inspections for space heaters of an effective rated output of more than 20 kW. This threshold was increased to 70 kW in the Directive 2018/844/EU. In Italy, the SH TBS inspection and control regulation was implemented in the Presidential Decree 74/2013, transposing the Directive 2010/31/EU. A new decree transposing the Directive 2018/844/EU will be published in the next few months. At the Italian level, 29% of total energy consumption is associated with the residential sector [7]. Natural gas use is higher than the European average, covering more than 50% of the residential consumption

(TABLE I). The analysis of the energy carriers by final use [8] shows that natural gas is the main fuel for both SH and DHW production, as more than 70% of TBSs are fed with it (TABLE II). This information is consistent with the diffusion of single boilers, mainly fed with natural gas.

Table 1. Total consumption of the Italian residential sector (in Mtoe) and its distribution by energy carrier according to [7]

	Total	**Oil**	**Natural gas**	**Renewables**	**Derivate heat**	**Electricity**
Residential (Mtoe)	30,364	1,883	15,680	6,152	879	5,770
%	-	6%	52%	20%	3%	19%

Table 2. Percentage distribution of the final energy use by TBS typology and involved energy carriers according to [9]

	Type		**Energy carrier**				
	Centralized	**Single**	**Oil**	**LPG (Liquefied Petroleum Gas)**	**Electricity**	**Natural gas**	**Biomass and renewables**
SH	15.7%	84.3%	3.7%	5.8%	5.1%	70.9%	14.5%
DHW	5.8%	94.2%	2.9%	7.7%	14.4%	71.9%	3.1%
Cooling	3.9%	96.1%	-	-	-	-	-

At the European level, developing a national digital register to collect data on TBSs characteristics, maintenance, and inspections, is not mandatory yet. Thus, there isn't the availability of nationals centralized specific data base able to give information on TBSs. This kind of information could be, in some extent, deduced by the Energy Performance Certificate (EPC), which often includes information on the existing final energy uses and the related TBSs. The majority of EU MSs have implemented a national EPC digital register. The new proposal for the EPBD revision would make it mandatory to develop a national EPC digital register which should include data on TBS inspections. Furthermore, this proposal would also ask MSs to transfer periodically the information collected in EPC digital registers to the Building Stock Observatory (BSO). Only a few MSs store the inspection reports in EPC databases so far, while, in others, some Regions voluntarily implemented a local and separate TBS register [8]. The Italian Presidential Decree 74/2013 issued the mandatory development of SH TBS registers for Regions and Autonomous Provinces. These local registers have been differently and their data are usually not public. Furthermore, the few TBS data collected in local registers are extremely heterogeneous. Therefore, the information on TBSs collected on EPC digital registers could provide a detailed overview of the national territory to overcome this data fragmentation.

The knowledge of the TBSs stock at local and national levels is crucial to developing suitable policies and monitoring the effectiveness of the existing ones. The previous literature based on the study of TBSs focuses mainly on the analysis of single technologies. A few of these works started from evaluating energy consumption for SH to implement models able to simulate different energy policy scenarios. Siksnelyte-Butkiene *et al.* [10] developed a methodology to compare the sustainability of the heating sector in 7 North European countries based on energy consumption data by energy carriers extracted from Eurostat 2020. Reuter *et al.* [11] studied the evolution of the energy consumption for SH in residential buildings in Germany and Switzerland. They used the ODYSSEE-MURE database and the national energy strategies to create an energy consumption baseline. Kannan and Strachan [12] and Dodds [13] implemented a model to simulate the application of energy policies in the UK to improve the estimation of future heat demand. They based the model on the heat generation technologies existing in the territory by extracting data from historical take-up or market surveys. Aydin and Brounen [14] used the International Energy Agency's (IEA) data on energy consumption for heating systems to analyze the impact of policies aiming at reducing household energy consumption. Finally, Van der Brom *et al.* [15] calculated the contribution of the occupants and the building through actual residential heating consumption in Netherlands and Denmark. Building characteristics and energy consumption data were defined by using the Netherlands Social Housing dataset, the Dutch National Statistics, the Statistical Denmark register, and the Danish Building and Dwelling Register.

The results of the previous works are based on aggregated datasets describing only a few parameters. EPCs are an important source of information on building characteristics, and their related final energy uses and TBSs. Extensive analyses of EPC data allow monitoring and evaluation of the building stock and the existing policies [16]–[27]. EPC digital registers collect and may combine EPC data to perform several parametric analyses on the certified building characteristics, including the ones of the final energy uses. Pasichnyi *et al.* [28] provide an extensive evaluation of the previous works focused on EPC data analysis finding that one of the most used parameters is the energy system characteristics [16]–[18], [21]–[23], [25]. However, this information was never used to map and evaluate the TBS stock of a certain area or the related energy policies. Gibbons and Javed [29] used the EPC register to find efficient HVAC solutions in Nearly Zero Energy Buildings (NZEBs) in Norway, Sweden, and Finland. To the authors' knowledge, no other examples of using EPC data for these purposes were found.

At the Italian level, the EPC template reports detailed data on installed TBSs, final energy uses, and their energy performance index. The national EPCs are transmitted to the Informative System on Energy Performance Certificates (SIAPE - Sistema Informativo sugli Attestati di Prestazione Energetica, in Italian), managed by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA). SIAPE allows the analyses of the building characteristics, such as the location and the main features of the TBSs, accordingly to different parameters. Furthermore, the integration process between SIAPE and the TBS data collected in the regional registers is started.

In this paper, EPC data contained in SIAPE are used for the first time to analyze and monitor the existing final energy uses and related TBSs in the Italian residential stock. This work aims to demonstrate how SIAPE and EPC registers can be considered valuable tools to evaluate the state of the art and the evolution of the energy certification. Furthermore, they allow combining information on buildings and energy systems. In this way, SIAPE becomes important to support the analysis and the implementation of suitable energy policies by:

- Analyzing the distribution of SH and DHW generators at the national and local levels.
- Finding correlations between climate conditions and the technologies installed on the territory.
- Evaluating the impact of the regulatory framework by combining the TBSs data with the construction period and the purpose for EPC issuing.

The potential of the data collected in national EPC registers strengthens the new perspectives indicated in the proposal revising the EPBD.

The paper is structured as follows. After the Introduction, basic knowledge about the Italian EPC scheme is provided, followed by a description of the main characteristics of the analyzed EPC sample and the investigated parameters. The third section shows in detail the results of this work, first providing information on the distribution of SH and DHW TBSs in the residential sector and then focusing on their evolution over time and depending on the energy regulatory framework. This section focuses deeply on the TBS powered by Renewable Energy Sources (RESs). Finally, the Conclusions summarize the research findings and draw their possible future developments.

Materials and methods

Overview of the Italian Energy Performance Certificate and the analyzed SIAPE sample

An overview of the Italian EPC scheme is provided below for a better comprehension of the results of this study and the potentialities of SIAPE. The current Italian EPC calculation methodology, template, and minimum requirements were established by the Ministerial Decree 26/06/2015 series, which implemented the Directive 2010/31/EU. Italian EPCs are mainly issued for building units or single-unit buildings, such as single-family houses, especially in the residential sector. Hereafter the word "dwelling" refers to building units or detached houses. Besides the energy label and the Global Energy Performance Indices (EP_{gl}), the EPC includes information on several aspects of the dwelling and the climate context where it is located: geometry and size, building type and use, the purpose for EPC issuing, thermal and energy characteristics, recommendations for improving energy savings, and existing final energy uses and related TBSs. More information on the Italian EPC regulatory framework and the EPC parameters can be found in [19]. Regions and Autonomous Provinces issue the EPCs and collect them in their local registers. Then, they transfer them to SIAPE, as established by the Ministerial Decree on 26/06/2015, implemented at the end of 2016. By April 2022, SIAPE contains more than 3,800,000 EPCs certifying residential and non-residential stocks. The EPCs are issued from 2015 to 2021 and uploaded by 16 Regions and 2 Autonomous Provinces, corresponding to 18 out of the 21 Italian regional Administrations. The EPCs collected in SIAPE can be consulted on the online Portal [30] developed by ENEA in 2020. The SIAPE Portal was implemented with a public section where aggregated analysis of national EPC data can be carried out without specific credentials.

According to the analysis carried out by [19], the SIAPE EPC sample is considered representative of the Italian building stock since it shows distributions similar to the national building census data. For this reason, it can be used to investigate the TBS equipment and characteristics of the Italian territory. However, not all the connected Regions provide information on TBSs; therefore, the SIAPE sample was reduced to about 2,700,000 EPCs. Furthermore, Italian EPC data go through a validation process composed of two steps: the first one performed by the Italian Thermotechnical Committee (CTI) and the second one by Regions and Autonomous Provinces. The sample used in this work underwent an additional control step carried out by ENEA, which excluded about 10% of the data from the analyses. This control verified the consistency of different parameters, such as climatic zone, dimensional data (heated volume and area, heat dispersant area), purpose for EPC issuing, construction year, building use, energy performance indices, and CO_2 emission, reducing the sample to 2,412,574 EPCs. More information on the controls performed on Italian EPCs can be found in [19].

As aforementioned, the selected EPCs describe the residential sector, which represents approximately 85% of the SIAPE sample (TABLE III), in agreement with the data of the censuses carried out by the Italian National Institute of Statistics (ISTAT - Istituto Nazionale di Statistica, in Italian) [31] and the Italian Centre for economic, sociological and market research in buildings (CRESME - Centro ricerche economiche, sociologiche e di mercato nell'edilizia, in Italian) [32].

Table 3. Percentage distribution of the building units by building use according to [30]–[32]

Building use	ISTAT	CRESME	SIAPE
Residential	84.4%	85.6%	85.9%
Non-residential	10.5%	14.4%	14.1%
Not occupied	5.1%	-	-

The EPC template includes several data on the final energy uses existing in the dwelling: SH, DHW, mechanical ventilation, space cooling, artificial lighting, and people and things transportation (such as elevators and escalators). Considering only residential dwellings and the SH and DHW final energy uses, the analyzed SIAPE sample includes the data shown in TABLE IV. According to the Ministerial Decree 26/06/2015, the calculation of SH and DHW is mandatory in residential dwellings, while artificial lighting and transportation must never be considered. Therefore, the TBS should be simulated if the mandatory final energy uses are not present. Therefore, all the analyzed dwellings are equipped with SH and DHW production systems, while only 16% are provided with TBSs for space cooling. Furthermore, mechanical ventilation is installed only in 1% of the sample. For this reason, the final energy uses and related TBSs analyzed in this work are focused only on SH and DHW.

Table 4. Number of occurrences of the analyzed EPC sample considering only the residential sector

Building use	Number of occurrences
EPCs	2,067,869
SH TBSs	2,265,506
DHW TBSs	2,153,884

Analyzed parameters

The EPC shows several data on the final energy uses. To evaluate SH and DHW final energy uses in the residential sector, this paper examines the followings:

- The number of installed TBSs which were classified accordingly to the final energy use of the different common technologies. Specifically for SH and DHW final energy uses, the TBSs can be selected by the EPC assessor among a list of limited choices: boilers (standard, condensing, and electric), water heaters, heat pumps (air-air, air-water, water-air, water-water), and woodstoves or fireplaces.
- Year of installation of the TBS.

- Energy carriers. They usually correspond to electricity, natural gas, LPG, oil, and solid biomass (specifically for woodstoves and fireplaces). EPCs report the calculated energy consumption for standard use for each energy carrier. Therefore, it is impossible to distinguish the final energy use of the single energy carrier.

- Effective rated output expressed in kW.

The previous parameters were investigated in combination with the location and the dwelling characteristics. First, the TBS distribution was evaluated by the climatic context where the dwelling is located. The Italian territory is characterized by heterogeneous atmospheric conditions, considering the discontinuity of its morphology. This variety leads to the classification of 6 climatic zones depending on the number of degree days of each Italian area: from A (the hottest) to F (the coldest). However, climatic zone A includes only two municipalities, and its characteristics are close to the one of climatic zone B. For this reason, the two climatic zones were analyzed together. The differences among climatic zones influence the dwelling energy performance and the type of installed TBS. After that, the analysis focused on the type of TBS installed in new constructions and major and minor renovations. This investigation, combined with the TBS installation year, provides information on the impact of the regulatory framework on the distribution of the type of energy systems. Finally, TBSs powered by RESs were investigated to provide detailed data about the RES distribution on the Italian territory and how the regulatory framework influences it.

Results and discussion

Energy system distribution

The most frequent TBSs used in the residential sector are analyzed in TABLE V. Almost 90% of SH systems and more than 80% of DHW systems are boilers. Heat pumps are usually installed in the Italian NZEBs [33], while their use in the other building categories is still uncommon. About 10% of TBSs installed for DHW production are water-heaters. Fig. 1 shows the previous results disaggregating also by climatic zone, confirming that the most widespread use of standard boilers, especially in climatic zones C, D, E, and F. TBSs feed by electricity, instead, are often employed in the hotter climatic zones (A and B), where the energy need for SH in winter is particularly low, and the energy demand for space cooling is higher. Finally, most of the woodstoves and fireplaces are installed in climatic zone F, the coldest. The high use of wood fuels in this area is due to the favorable fuel supply conditions by the local wood chain. Moreover, stoves and fireplaces are the traditional SH systems in the mountain areas of Italy, where wood logs were also used in cooking appliances. As a consequence, and according to [7], [9], natural gas is still the most used energy carrier (TABLE VI), except for climatic zones A and B, where there is a widespread use of heat pumps. Approximately, woodstoves and fireplaces are considered space heaters based on RES use which are considered the energy carrier used in more than 10% of dwellings in climatic zone F.

Table 5. Percentage distribution of type of installed TBSs for SH and DHW

TBS	SH	DHW
Standard boiler	58.6%	46.8%
Condensing boiler	28.3%	19.5%
Woodstove or fireplace	3.1%	0.4%
Heat Pump	6.5%	3.0%
Water-heater	0.0%	10.2%
Electric boiler	0.4%	16.8%
Other	3.1%	3.3%

Figure 1. TBSs percentage distribution by climatic zone: SH (left) and DHW (right)

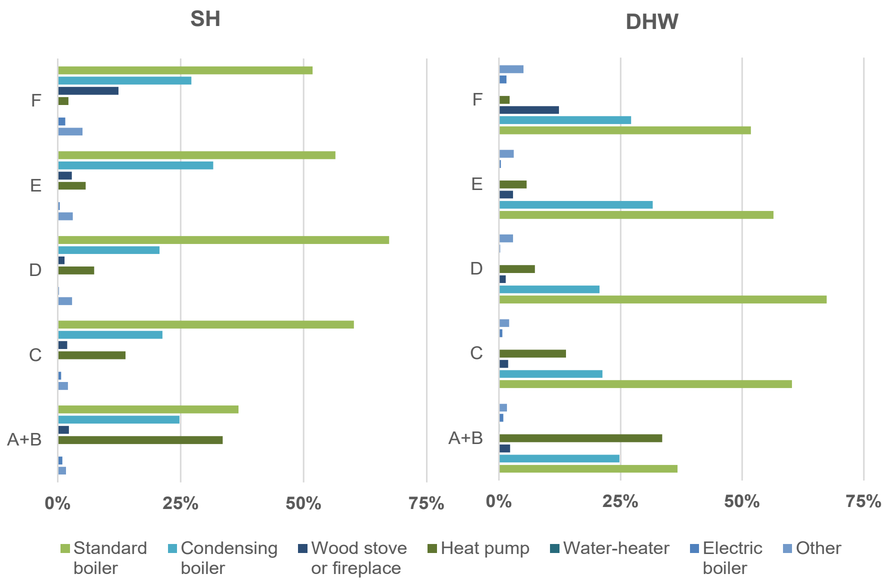
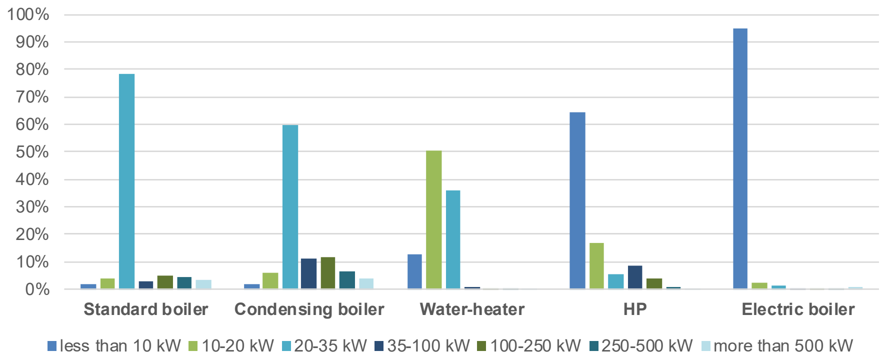


Table 6. Percentage distribution of the energy carriers feeding SH and DHW TBSs by climatic zone

Energy carrier	Climatic zone				
	A+B	**C**	**D**	**E**	**F**
Electricity	56.3%	27.4%	20.3%	11.6%	17.9%
Natural gas	38.3%	64.8%	74.2%	78.5%	41.5%
LPG	3.8%	4.7%	2.6%	1.5%	8.2%
Diesel	0.2%	1.0%	0.6%	1.4%	16.4%
RES	1.1%	1.9%	1.5%	3.1%	10.7%
Other	0.2%	0.2%	0.8%	3.9%	5.3%

The most common TBSs used for SH and DHW by the range of effective rated output declared in the EPC are analyzed in Fig. 2. The distribution highlights the prevalence of single space heaters over centralized systems. Almost 80% of standard boilers and almost 60% of condensing boilers are characterized by an effective rated output between 20 and 35 kW, which corresponds to SH supplying single dwelling energy demand. The average seasonal energy efficiency of these two technologies is about 65% and 75%, respectively, according to the analysis of SIAPE data in the residential sector. Effective rated output values over 100 kW are typical in central heating systems providing energy for condominiums. Centralized boilers (over 100 kW) are standard in less than 15% of the sample and condensing for approximately 20%. TBSs using electricity (electric boilers and heat pumps) are characterized by an effective rated output lower than 12 kW. In the Italian Presidential Decree 74/2013, 12kW is the maximum threshold to activate mandatory controls for cooling systems, while the threshold for space heaters is set at 10 kW. Half of the water-heaters have an effective rated output of between 10 and 20 kW and are involved only in DHW production.

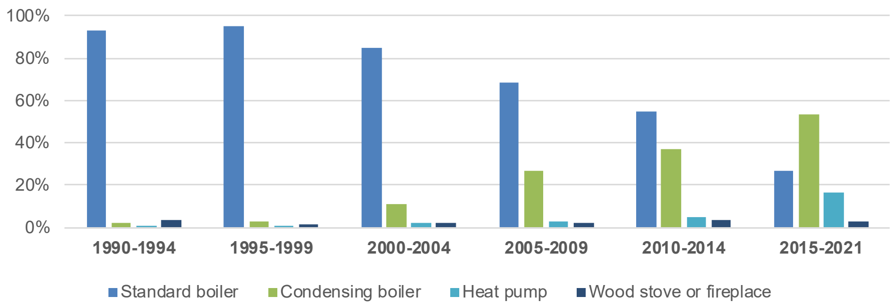
Figure 2. TBS percentage distribution by effective rated output ranges



Impact of the regulatory framework on Technical Building System equipment for Space Heating

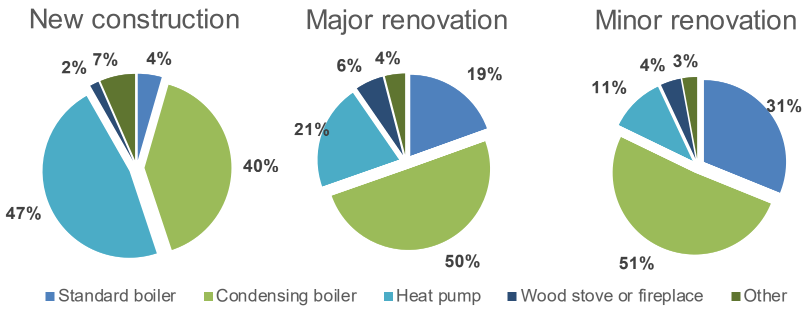
The selected TBSs were analyzed by year of installation (Fig. 3), providing useful information on the evolution of TBS equipment in the Italian building stock. The life cycle of a TBS is usually around 10–15 years, even if it could achieve 20-25 years for centralized heaters. For this reason, installation years before 1990 were not included in the analysis. Between 1990 and 1999, more than 90% of the TBS equipment is represented by standard boilers. After this period, the use of standard boilers started to decrease in favor of condensing boilers due to the European Ecodesign Directive (2009/125/EC), forbidding the marketing of traditional boilers. This regulation established that only efficient boilers (e.g., condensing ones) can be placed on the market after September 2015. Despite this Directive, the percentage of standard boilers installed after 2015 is still more than 25%. Traditional space heaters are still installed especially in multi-family houses, where their replacement is more difficult due to the differences in the evacuation gas systems between standard and condensing boilers. The use of heat pumps grew very slowly until 2014; then, their installation is more than triplicated from 2015 to 2021. Finally, woodstoves and fireplaces are installed approximately in 3% of the analyzed EPC sample.

Figure 3. TBS percentage distribution by installation period



TBS equipment was also investigated through the purpose for EPC issuing, especially for the categories "new construction", "major renovation", and "minor renovation" (Fig. 4), according to the definitions issued by the Ministerial Decree 26/06/2015 series. Heat pumps as heating technology have an important role in the Italian National Energy and Climate Plan to facilitate the diffusion of production by RES in the building sector. This fact is shown in Fig. 4 where new constructions are mainly equipped with heat pumps (47%) and condensing boilers (40%). The percentage of heat pumps is halved in major renovations (21%), and it is even lower in minor renovations (11%). Half of the installed heating TBSs in these two categories are condensing boilers; however, the equipment with standard ones is still high (19% in major renovations and 31% in minor renovations). Thanks to the high efficiency of heat pumps and the possibility to couple them with photovoltaic systems, this technology is often used to meet the current energy requirements for new buildings and in case of deep renovation. High energy performance can also be achieved in new buildings with condensing boilers combined with heat pumps and solar thermal panels [19].

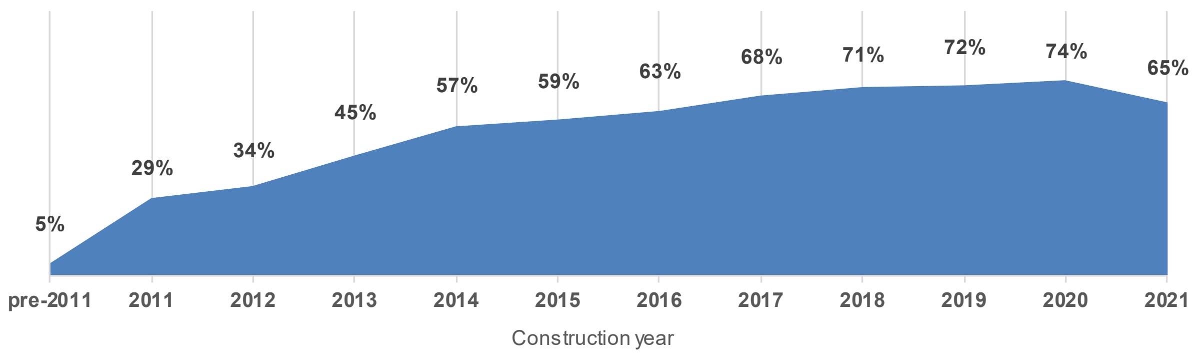
Figure 4. SH TBS percentage distribution for new construction, major and minor renovations



Production from Renewable Energy Sources

The last set of analyses was focused on TBSs powered by RESs. The represented data are extracted by a specific domain of the EPC template on TBSs producing energy from RES on-site or nearby; this domain provides information on the type of system, the year of installation, the energy carrier, and the effective rated output. Less than 10% of the analyzed EPCs show information on existing RES systems. RES system installation is regulated by the Italian Legislative Decree 28/2011, which implements the Directive 2009/28/EC. This law set specific requirements for new buildings, including those undergoing demolition-reconstruction and buildings undergoing relevant renovations, where RESs should contribute to 50% of the energy need. The impact of the Legislative Decree 28/2011 was evaluated by comparing the number of certified buildings with and without TBSs powered by RESs and built before and after 2011 (Fig. 5). This analysis does not consider EPC issued for minor or major renovations. The results show the positive impact of the law with a sudden increase from 5% to 29% after 2011 of dwellings equipped with RES systems until the maximum peak of 74% in 2020. The decrease in 2021 can be attributed to incomplete data availability.

Figure 5. Percentage distribution of the buildings equipped with at least one TBS powered by RESs by construction year



Considering residential EPCs showing at least one TBS fed by RES, energy production from RESs is mainly provided by heat pumps (30%), followed by solar-thermal systems and photovoltaic systems (28%) and woodstoves and fireplaces (14%) (TABLE VII). Production from wind energy is almost not used and the district heating powered by RESs is uncommon and located mainly in the climatic zone F. As for the previous results, heat pumps are mostly equipped in dwellings located in climatic zones A and B, and woodstoves and fireplaces are mainly installed in climatic zone F.

Table 7. Percentage distribution of installed RES systems by climatic zone

	A+B	C	D	E	F	TOT
Woodstove or fireplace	2.9%	4.0%	4.9%	13.3%	41.7%	12.5%
Heat pump	49.4%	29.6%	19.2%	34.6%	6.5%	29.8%

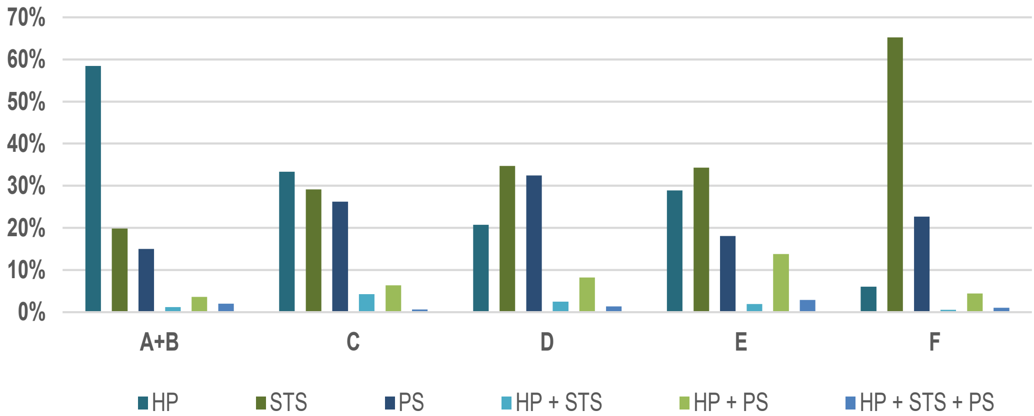
	A+B	C	D	E	F	TOT
Solar-thermal system	24.8%	33.4%	36.9%	25.0%	32.9%	28.7%
Photovoltaic system	22.9%	33.0%	38.9%	26.7%	17.6%	28.6%
District heating	0.0%	0.0%	0.1%	0.3%	1.3%	0.3%
Wind system	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%

The study goes on focusing on the analysis of heat pumps, solar-thermal systems, and photovoltaic systems. TABLE VIII shows that the combination of these systems is used in approximately 15% of the certified dwellings. The same analysis was carried out also disaggregating the results by climatic zone (Fig. 6). Approximately 65% of the dwellings in climatic zone F are equipped only with solar-thermal systems, and this percentage decreases to about 30-35% in climatic zones C, D, and E. The use of photovoltaic systems alone covers from about 15% to 25% of the dwellings except for the climatic zone D, where they reach more than 30%. Only in this climatic zone the installation of heat pumps coupled to photovoltaic systems reaches almost 15% of the analyzed cases.

Table 8. Percentage distribution of the buildings equipped with heat pumps (HP), solar-thermal systems (STS), photovoltaic systems (PS), and their combination

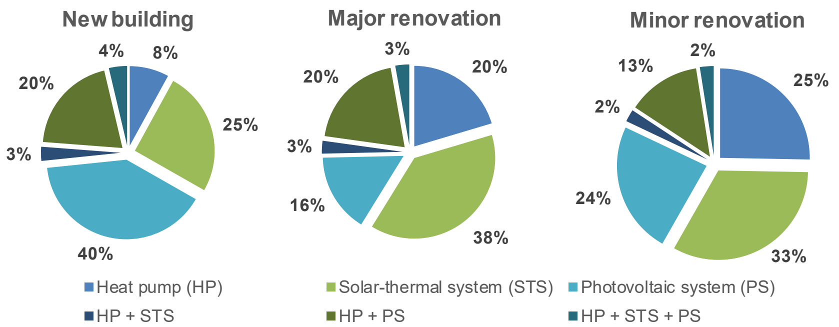
HP	STS	PS	HP + STS	HP + PS	HP + STS + PS
27.1%	35.2%	21.7%	2.2%	11.6%	2.3%

Figure 6. Percentage distribution of the buildings equipped with heat pumps (HP), solar-thermal systems (STS), photovoltaic systems (PS), and their combination by climatic zone



The equipment with heat pumps, solar-thermal systems, and photovoltaic systems was also investigated for the building categories subjected to the RES requirements set by the Legislative Decree 28/2011 (Fig. 7). Considering the EPCs showing RES production only, the use of heat pumps alone is very low in new buildings (less than 10%) in favor of installing photovoltaic and solar-thermal systems (40% and 25%, respectively).

Figure 7. Percentage distribution of new buildings and major and minor renovations equipped with heat pumps (HP), solar-thermal systems (STS), photovoltaic systems (PS), and their combination



The installation of the photovoltaic system alone increases in major and minor renovations (16-24%), while solar-thermal systems are more common than in new buildings (from 33% to 38%). Only the coupling of heat pumps and photovoltaic systems reaches good percentages among the combination of the RES systems: 20% of installation in new buildings and major renovations, and 13% in minor renovations.

Conclusions

This work presented an overview of the space heating (SH) and domestic hot water (DHW) Technical Building Systems (TBSs) existing in the Italian residential sector. This research aims to demonstrate the potential of the combined analysis of Energy Performance Certificate (EPC) data in providing useful information to monitor the TBS stock and the related policies. In the previous literature, indeed, the EPC data were mostly used to evaluate the energy performance of the building stock and monitor existing and future energy policies. Furthermore, the previous works on the study of TBSs were mainly focused on and analyzed single technologies and based their results on datasets composed of few parameters. The results of this paper are obtained from the evaluation of 2,067,869 residential EPCs collected in SIAPE, the Italian national EPC digital register managed by ENEA. The selected EPCs were issued from 2015 to 2021 by 16 Regions and 2 Autonomous Provinces.

The analyses performed on the SIAPE EPC sample assess how the Italian policies are achieving the European targets on energy savings and Renewable Energy Sources (RES) system use. Boilers powered by natural gas are about 85% of the installed TBSs for SH and DHW; most of the Italian dwellings are still provided with standard boilers whose seasonal energy efficiency is lower than the one of condensing boilers. Heat pumps are used to heat 6% of the Italian dwellings, and solid biomasses are used as the main fuels in the 3% of domestic appliances and only for woodstoves and fireplaces. These values increase in new buildings where heat pumps are used as heating systems for 42% of the analyzed dwellings; however, they are still uncommon in dwelling equipment after renovation, where the condensing boilers are predominant (50%). Furthermore, these results underline how far we are from the decisive technological shift toward solutions facilitating the penetration of renewable sources and the increase in energy savings. The analysis of new buildings provides an overview of the most used technologies for achieving the targets on energy performance and renewable energy. Heat pumps and electric boilers for DHW are frequently used in the hottest climatic zones. Standard and condensing boilers are mostly installed for both final energy uses in climatic zones C to D. Generally, the Italian residential dwellings are equipped with single heating systems with an effective rated output between 20 kW and 35kW. This range is typical for space heaters supplying energy in single dwellings. Electric boilers for DHW production are characterized by lower effective rated outputs (less than 10 kW). Heat pumps are common in new construction since they meet the minimum requirements mandatory for this category of buildings and the ones undergoing deep renovation. According to the analysis of RES use, heat pumps are coupled with photovoltaic systems in about 15% of the examined cases, concentrated in the climatic zone E. This percentage increases to about 20% when the evaluation is focused on new and major renovated buildings. Solar-thermal and photovoltaic systems alone are installed in about 35% and 21% of houses, respectively. The paper also analyzed the effect of the energy regulatory framework, especially the requirements asked by the Ecodesign Directive 2009/125/EC and of the Italian Legislative Decree 28/2011. The first one evidences the widespread of condensing boilers starting from 2015, and the second one shows the increasing trend of RES installations in dwellings built after 2011.

The paper shows that the EPC data examination allows combining of TBS data with other relevant information on the building, such as the construction year and the purpose for EPC issuing. In this way, this research opens to new information to monitor and evaluate the TBS stock at national and local levels. These results demonstrate that national digital registers of EPCs can be a good support for policymakers to define and monitor building renovation strategies. This analysis methodology is also in agreement with the new EPBD proposal, which will strengthen the role of national building databases. In fact, according to this proposal, national building databases will be mandatory, interoperable, and integrated with other administrative databases. They would also allow gathering data related to EPCs, TBS inspections, building renovation passports, smart readiness indicator (SRI), and calculated or metered energy consumption.

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Technology Campaigns: Adapting Commercial Building Strategies to the Residential Sector

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Abstract

The Department of Energy has successfully designed and delivered technology campaigns to the commercial building sector for decades. Technology campaigns are collaborative initiatives designed to help speed the adoption of new or underutilized energy-saving technologies by providing resources helpful to decision makers, technical assistance, and recognition of exemplary projects.

In 2019, participants in three Department of Energy technology campaigns focused on interior lighting, HVAC rooftop units, and energy management systems estimated that energy savings totaled over $250 million dollars. For example, from 2015 through 2019, the Interior Lighting Campaign focused on speeding the adoption of high-efficacy lighting options in commercial spaces. The result was 800 million kilowatt-hours energy savings from 92 campaign participants, 10 case studies published, and the installation of 3.5 million high-efficacy luminaires.

This paper reviews lessons learned and best practices from past and current technology campaigns focused on commercial buildings and describes how they are being applied to the design of two residential-focused technology campaigns. The first new campaign, the Smart Tools for Efficient HVAC Performance Campaign, is focused on increasing the adoption of smart diagnostic tools that HVAC technicians use while installing or maintaining residential HVAC equipment. These tools enable the technician to easily identify and correct system faults, leading to improved performance of the system. The second campaign is the Storm Window and Insulating Panel Campaign, which is focused on increasing adoption of low-emissivity interior and exterior storm windows.

This paper also will discuss opportunities and challenges to program design related to technology campaigns that seek to target the residential building sector and sectors that possess both commercial and residential elements, such as multi-family and small commercial buildings. Finally, the paper will discuss technology campaign strategies to address emerging goals, such as international coordination, social justice and reaching disadvantaged and underserved communities, workforce development, and carbon reduction.

Background and Introduction

The Department of Energy (DOE) Building Technologies Office (BTO) has sponsored numerous competitions to engage stakeholders and leverage ongoing research to speed the development and uptake of more efficient products or energy-saving approaches. Technology campaigns are one type of competition employed by DOE that are intended to speed the adoption of emerging or underutilized technologies, such as energy-efficient equipment, systems, or energy-saving materials or approaches, by identifying and overcoming market adoption barriers; creating awareness of new technology; providing technical assistance to support early adopters; recognizing successful applications of the technology; documenting energy savings and performance; and leveraging a diverse set of partners to provide outreach and support (Sandahl, 2020). DOE is in a unique position to design and develop technology campaigns in partnership with industry and other collaborators who represent a broad array of stakeholder groups. By serving as a neutral third party and as a technical contributor, DOE can work with partners to address barriers to adoption at a national scale versus regionally, and provide a platform for broadly sharing information and resources.

Over the years, campaigns have focused on technologies, such as advanced rooftop units (RTU), high-efficiency parking lot lighting, high-efficiency indoor lighting, smart energy analytics, envelope technologies, and advanced/integrated lighting systems. For more information on DOE competition approaches, including technology prizes, technology challenges, technology procurement, and technology campaigns, see *The Role of Competitions in Speeding Energy-Efficient Technology Development and Adoption* (Sandahl, 2020).

In 2021, DOE introduced two campaigns focused on residential sector: Storm Window and Insulating Panel Campaign (SWIP), designed to increase adoption of low-emissivity (low-e) interior and exterior storm windows; and the Smart Tools for Efficient HVAC Performance Campaign (STEP), designed to increase adoption of smart diagnostic tools that improve the operation of residential HVAC equipment during installation or maintenance by detecting system faults and recommending corrective actions to fix those faults.

DOE commercial building-focused campaigns target early adopters, including building owners and managers, who are somewhat knowledgeable about building science and who often influence large building portfolios. Building owners and managers typically consider proven products. Campaigns are designed to demonstrate real-world savings and other benefits, such as resources that make it easier for buyers to consider new or underutilized products and solutions. They also inform technology developers of real-world performance, user feedback, and opportunities for technology improvement. Campaigns focused on residential technologies, however, require a different programmatic approach. This paper describes how best practices and lessons learned from DOE commercial building focused technology campaigns can be applied to campaigns targeting residential sector technologies and purchasers.

Commercial-Focused Technology Campaigns

There are several reasons for launching a campaign, but essentially it boils down to helping overcome technical and market barriers associated with a given technology to help speed market adoption (Table 1). Technology campaigns can be designed to support both new or underutilized technologies and can serve as a platform to support products that emerge from technology prize, procurement, or challenge efforts (Sandahl, 2020). Like these other competition approaches, they rely heavily on market and industry input and involvement. Since 2012, DOE has partnered with efficiency groups and industry on four completed commercial-focused campaigns: 1) the Lighting Energy Efficiency in Parking Campaign (LEEP), focused on high-efficiency parking facility lighting; 2) the Interior Lighting Campaign (ILC), focused on high-efficiency interior lighting; 3) the Advanced Rooftop Unit Campaign, focused on high-efficiency RTUs with advanced controls; and 4) the Smart Energy Analytics Campaign, focused on energy management and information systems. More recently, two campaigns were launched and are currently active: 5) the Integrated Lighting Campaign, focused on advanced lighting controls and integration with other systems; and 6) the Building Envelope Campaign, focused on high performance building envelope technologies.

DOE considers a number of factors when deciding to introduce a technology campaign. They include the energy-savings potential of the technology if adopted at scale; the types of barriers faced; and the expressed interest of key stakeholders (e.g., large buyers, energy service companies [ESCOs], utilities, efficiency groups, and national or regional organizations that support these groups).

The key measure of success for a DOE campaign is the resulting energy savings. In most cases, the energy savings are directly quantifiable and documented in the campaign. For example, replacing a luminaire that consumes a fraction of the energy of an installed, or code-required baseline, luminaire allows calculating the actual energy saving impact directly given the energy use of each luminaire (e.g., a 13-watt compact fluorescent lamp replacing a 60-watt incandescent lamp). At times, however, the impact may be more indirect and harder to capture/measure without significant measurement and validation efforts. One example is from the integration of building systems by using smarter, more connected technologies. While sensors used for lighting may help inform other building systems, such as HVAC, quantifying of the actual energy savings resulting from such interactions is challenging to capture via the campaign. Campaigns, however, can take alternative approaches to capture, or estimate, the energy saving potential of a technology through data provided by campaign partners, such as building owners and utilities. The Integrated Lighting Campaign, launched in mid-2020, focuses on interactions between energy consuming building systems and captures estimated energy savings in systems leveraging lighting sensor data for several projects, including incentive data from several utilities, which can help establish the level of adoption and interest in the technology.

Table 1. Barriers to Adoption Addressed by Commercial DOE Campaigns

Barrier	**Campaign Solution**	**Example: Interior Lighting Campaign**
Benefits / business case not well understood	Clearly define the business case for adoption of the solution (product, process, system, etc.) using criteria that is important and relevant for each key stakeholder. Document resources that may include field validation findings, case studies, and testimonials. As a neutral third party, DOE is in a unique position to research and document this information.	Developed several case studies across different building sectors demonstrating the benefits and business case for recognized exemplary installations adopting high-efficacy luminaires that meet the campaign requirements. [a]
No easy way to distinguish between product offerings	Establish minimum campaign requirements for products/ systems/solutions. Encourage the use of performance specifications, such as those developed by DOE or by a third party. Link to more information where possible, making this information easy for campaign participants to find.	Encouraged use of the DOE "High-Efficiency Troffer Specification" and provided links to DOE and other third-party resources, including CALIPER and GATEWAY reports, which are informed about product and system performance.
Lack of awareness regarding benefits	Assess and capture the energy and nonenergy benefits to ensure they are communicated and considered by decision makers. Particular attention is given to higher value propositions that can entice technology adoption, such as: • Labor savings, both at installation and throughout the lifetime of the product; • Maintenance savings, such as reduced need for consumables; and • Operational savings from new technologies (e.g., Bluetooth) integrated into products.	Obtained partner information regarding project costs (e.g., payback periods), anticipated/measured benefits, and other benefits observed (e.g., nonenergy benefits). These are shared with others via case studies to increase awareness.
Upfront cost is high / difficult to find utility program incentives	Consolidate information on utility program offerings.	Developed and maintained a list of incentives from partner utilities and also provided links to DSIRE database. [b]
Too difficult to install and / or commission	Technical assistance is available from subject matter experts at national laboratories.	Worked with several partners who were performing lighting upgrades to provide recommendations on items to consider when selecting between multiple offerings, leveraging the experience of national laboratory research conducted at the product, system, and building levels.

Barrier	Campaign Solution	Example: Interior Lighting Campaign
Lack of general awareness of technology / product / solution	Recognition of exemplary projects provides a public forum to expose other peer building owners to the technology.	Conducted several events to recognize exemplary projects in public forums (e.g., partner annual conferences and DOE events), providing exposure to the benefits observed by building owners from adoption of high-efficiency lighting and controls.
Lack of confidence in real-world savings	Recruit building owners from a broad range of sectors and locations to create relatable examples for a variety of decision makers and climates.	Encouraged project submissions across a broad range of building sectors. Recognized projects and developed case studies to which others could relate.

[a] Case studies archived at https://betterbuildingssolutioncenter.energy.gov/interior-lighting-case-studies.

[b] Database of State Incentives for Renewables & Efficiency (DSIRE) is a public service center managed by the North Carolina Clean Energy Technology Center.

To date, DOE and its partners have hosted eight campaigns. Four of those campaigns are retired and four are currently active (two commercial and two residential). Retirement of a campaign does not mean that the technical and market barriers no longer exist. It often means that market adoption has improved, that sufficient knowledge has been collected and documented from campaign participants, and that DOE's market support role is no longer critical. This may result from evidence of a market that is transforming on its own. For example, the ILC was retired in 2019, when it became clear that the market adoption of LEDs in key interior applications was well underway. Leadership of a campaign may also be transitioned to another entity once market adoption begins to take off. For example, LEEP, introduced by DOE in 2012, was later led and managed by the U.S. Green Buildings Council from 2017 – 2019 until it was retired. Once a campaign is retired, the resources developed to support market adoption are consolidated into "toolkits," containing information from resources developed during the execution of the campaign (e.g., case studies, specifications, reports, etc.). Table 2 lists DOE campaigns, their focus areas, years of execution, and outcomes.

Table 2. DOE Commercial Building Campaigns

Campaign	Focus Area(s)	Timeframe	Outcomes
Advanced Rooftop Unit Campaign	High-Efficiency RTU	2013 – 2019	• Over 1B kWh/yr savings • \$110M/yr savings • 23 partners recognized • 160,000 RTUs impacted • RTU Specification • Toolkit • Influenced RTU levels in building code
Building Envelope Campaign [a]	Building Envelope (Windows, Walls, Roofs)	2020 – Present	Recognized 14 projects accounting for 1.5M ft^2 of conditioned floor area in the first year
Interior Lighting Campaign (ILC)	Interior Commercial Lighting and Controls	2015 – 2019	• 880M kWh/yr savings • \$84M/yr savings • 51 partners recognized • 3.5M luminaires impacted • "High-Efficiency Troffer Performance Specification" • Toolkit
Integrated Lighting Campaign [a]	Advanced Lighting and Controls	2020 – Present	Recognized 20 partners in 2021, published nine case studies

Campaign	Focus Area(s)	Timeframe	Outcomes
Lighting Energy Efficiency in Parking (LEEP) Campaign	Parking Facility Lighting and Controls	2012 – 2017	• 229M kWh/yr savings • $24M/yr savings • 565M ft^2 of parking facilities • "High-Efficiency Parking Structure Lighting Specification" • Toolkit
Smart Energy Analytics Campaign	Energy Management and Information Systems	2016 – 2020	• $95M/yr savings • Recognized 29 partners • 600M ft^2 of floorspace • "Energy Management and Information System Specification" • Toolkit

[a] Campaign currently in progress; first year outcomes shown

Commercial Campaign Example: Interior Lighting Campaign (ILC) (2015 – 2019)

To provide an example of the genesis, design, execution, and outcomes of campaigns, the ILC is described in this section.

The lighting industry was experiencing a dramatic shift from low-efficacy lamps and luminaires to high-efficacy light-emitting diode (LED) technology in the early 2000s. In commercial spaces, although troffer luminaires used fluorescent lamps that were relatively efficient, LEDs were offering several options to reduce energy and improve lighting performance—these included LED tubes, retrofit kits, and luminaires. The plethora of options available to building owners wanting to explore lighting upgrades or new installations was creating confusion and a barrier to greater adoption of more efficacious and controllable lighting technologies.

The ILC was launched to consolidate useful implementation guidance and resources to building owners, recognize exemplary projects doing it right, and provide expert technical assistance from DOE national laboratories. Its initial focus was troffer luminaires, given the dominance in commercial lighting spaces and manufacturers' focus on this growing market opportunity. Over the years, the ILC grew to include other indoor luminaires, such as suspended linear, low bay, and high bay. A website provided resources from several third parties (e.g., national laboratories, energy efficiency organizations, utilities, etc.), including ILC-developed case studies, and served as a platform to recognize exemplary projects. Two key resources served as guidance to ILC partners. The "High-Efficiency Troffer Performance Specification" published by DOE provided building owners with performance characteristics to consider when specifying lighting for their projects. Also, the Lighting Project Evaluator tool allowed users to estimate the potential energy savings resulting from a lighting upgrade and served as a means to submit the necessary data (i.e., luminaires and controls removed/installed) to be considered for ILC recognition.

During its tenure (2015 – 2019), the ILC documented the adoption of 3.5 million high-efficacy luminaires, resulting in nearly 800 million kWh yearly energy savings. The ILC also conferred 51 recognitions for exemplary performance and published 10 case studies from ILC-recognized projects. Resources from the ILC were archived in the Better Buildings Solution Center to serve as information for projects considering lighting upgrades beyond the lifetime of the campaign (Better Buildings Solution Center, 2021).

Public-Private Collaboration – Leveraging Partners for Success

DOE commercial building campaigns are executed during the early days of adoption of a given technology; therefore, it can be challenging to identify and recruit building owners who have installed the technology in their facilities. Campaigns document performance of the projects submitted and recognize exemplary performance to show a technology's potential and encourage others, especially peers, to consider it sooner than might otherwise be the case. To help in this regard, campaigns rely on public-private collaboration and have leveraged three key partner types referred to as organizers, supporters, and participants. Table 3 provides an overview of these partner types and their roles.

Table 3. Campaign Partner Types and Their Roles

Partner Type	Description	Main Roles in Campaigns
Organizers	Key industry organizations with a vested interest in energy savings or increasing the uptake of the technology in support of their members or constituency. These are often trade or professional groups with broad reach and influence that can help the campaign achieve its goals.	Organizers agree to contribute to the design and management of the campaign and serve as a champion within their organization and its partners/members to create awareness and encouraging participation, including the submission of projects/efforts for recognition. Commercial campaign examples: Building Owners and Managers Association, International Facility Management Association, Illuminating Engineering Society, and American Society of Heating, Refrigerating and Air-Conditioning Engineers.
Supporters	Broad range of industry players, such as utilities, energy efficiency organizations, manufacturers, distributors, designers, etc. This partner type is open to all organizations aligned with campaign goals and agree to support its efforts. In general, supporters provide a product or service to participants, or support the adoption of the technology through their efforts (e.g., research, education, etc.).	Supporters serve as a critical source of outreach to expand campaign recruitment efforts for both participant partners to join and for identifying and getting projects submitted for recognition consideration. Supporters receive the indirect benefit of product and services exposure as part of case studies and other collateral developed by the campaign, such as newsletters, presentations, and webinars. Recognition may be conferred for exemplary supporter efforts, such as to catalyze adoption of the technology or for providing data/support to the campaign (e.g., recruiting, incentive data, etc.).
Participants	Building owners, facility managers, and others are closely invested/involved in the day-to-day operation/maintenance of the technology within a building.	Participants are organizations that use or deploy the technology. For the commercial building sector, these are typically building owners and managers.

Applying the Campaign Model to the Residential Sector

The technology campaign framework has proven successful for speeding the adoption of energy-efficient technologies in the commercial sector, but a large opportunity for energy efficiency also exists in the residential sector. In 2020, the residential sector accounted for 22 percent of United States primary energy consumption and the commercial sector accounted for 18 percent (U.S. Energy Information Administration, 2021). With the large untapped energy savings opportunity in homes, applying the commercial campaign framework to the residential sector could be very impactful. For instance, energy-efficient upgrades result in utility bill savings for homeowners and renters, reduced peak demand for utilities, and reduced greenhouse gas emissions which benefits society at-large.

Key components of commercial building technology campaigns, developed and refined based on lessons learned from prior technology campaigns (Sandahl, 2020), can also be applied to the residential sector. Components of the campaign framework include:

- Identifying key technical and market adoption barriers and the existing or new solutions for addressing them;
- creating awareness of the new technology, including advantages, challenges, best use cases, etc.;
- providing technical assistance to support early adopters;
- recognizing successful applications of the technology;

- documenting energy savings and performance; and
- leveraging a diverse set of partners to provide outreach and support.

Two new DOE campaigns, the Smart Tools for Efficient HVAC Performance Campaign (STEP) and the Storm Window and Insulating Panel Campaign (SWIP), are applying the commercial campaign framework to the residential sector. Translating the framework presents some challenges – primarily, the key stakeholders are different in the residential sector as illustrated in Table 4. In the commercial sector, the primary stakeholder group targeted is often building owners and managers since they typically make purchase decisions and are involved in the day-to-day operation of the building. In the residential sector, ownership is highly distributed and energy savings per property are smaller. Homeowners tend to be the ultimate decision maker but are hard to reach as a group, and often rely on others (like contractors) to present them with home efficiency improvement options. An added challenge unique to the STEP Campaign, is that homeowners benefit from the application of smart diagnostic tools; however, the HVAC contractor, installer, or service technician is the entity that makes the purchase decisions. A critical stakeholder group unique to residential campaigns are weatherization agencies funded by DOE's Weatherization Assistance Program (WAP). WAP targets low-income households to improve home energy efficiency as well as health and safety. To ensure energy efficiency technologies are deployed equitably, engaging with weatherization agencies has become an important aspect of both residential campaigns. Other stakeholders that need to be targeted in both commercial and residential campaigns are utilities and energy efficiency program providers, manufacturers, and federal buildings.

Understanding value propositions for implementing energy efficiency technologies or participating in a technology campaign must be considered for residential campaign stakeholders. The commercial campaigns use recognition at a national event to foster participation in the campaign from building owners and managers, utilities, efficiency program implementers, and ESCOs; however, residential sector stakeholders tend to operate at a more local level and may not value national recognition. Ultimately, feedback from residential market actors is needed to understand pain points, value propositions, and which organizations to engage to drive participation in the campaign.

Table 4. Key Stakeholders – A Comparison of Residential and Commercial Campaigns

Stakeholders	Residential		Commercial		
	STEP	SWIP [a]	SWIP	ILC	Advanced Rooftop Unit Campaign
Residential HVAC contractors	X				
Commercial HVAC contractors					X
Home performance contractors	X	X			
Commercial building owner/ managers			X	X	X
Multi-family building owner/managers (low-rise)	X	X		X	X
Multi-family building owner/managers (high-rise)			X		
Federal buildings	X[c]	X	X	X	X
Residential homeowners [b]	X	X			
Home builders	X				
Utility or efficiency program provider	X	X	X	X	X
Product or solution provider	X	X	X	X	X
ESCO			X	X	X
Architect, designer, engineer				X	X
Weatherization agencies	X	X			

[a] SWIP includes residential (storm windows).
[b] Residential homeowners are difficult for any campaign to reach.
[c] Federal buildings that use light commercial or residential HVAC equipment.

The following section describes the STEP and SWIP campaigns in more detail. The STEP Campaign aims to improve the installed performance of central air conditioners and heat pumps by increasing the adoption of smart diagnostic tools that help HVAC technicians and installers troubleshoot residential HVAC systems and ensure the systems are installed and maintained without energy-wasting faults, such as improper refrigerant charge or airflow. The SWIP Campaign aims to "leave no poor-performing window uncovered" by increasing the adoption of low-e storm windows and insulating panels in applications where full window replacement is not viable.

Smart Tools for Efficient HVAC Performance Campaign (STEP)

Space heating and cooling systems account for 44 percent of total primary energy consumption in United States residences and represent a large opportunity for carbon and energy savings (U.S. Energy Information Administration, 2020). The residential HVAC system stock is dominated by central air conditioners (CAC) and air source heat pumps (ASHP). According to U.S. Energy Information Administration (EIA) estimates, 64 percent of homes in the United States use CACs for cooling (U.S. Energy Information Administration, 2015) and 11 percent of homes use heat pumps for both heating and cooling (U.S. Energy Information Administration, 2015). Beginning in 1992, CAC/ASHP equipment was required to meet federal minimum standard efficiencies that have been steadily raised by DOE over time. For example, in 1992, the minimum seasonal energy efficiency ratio (SEER) for residential cooling systems was 10 SEER. The new standards effective in 2023 will require 16 SEER cooling equipment in the Southeast and Southwest, and 14 SEER for the rest of the United States (U.S. Energy Information Administration, 2019). For heating in 1992, DOE required a minimum heating seasonal performance factor (HSPF) of 6.8. Currently, the minimum HSPF is 8.2 and the new 8.8 HSPF will go into effect in 2023 (U.S. Energy Information Administration, 2019).

Although minimum equipment efficiencies have increased over time, equipment faults imposed during installation or maintenance negatively impact equipment efficiency, leading to energy waste, comfort issues, and equipment reliability concerns. Improper installation is a common problem in the residential sector. A recent meta-analysis by DOE revealed at least one energy wasting fault in 70 – 90 percent of homes (DOE 2018). A report by the National Renewable Energy Laboratory estimated that two prevalent installation faults (inadequate airflow and improper refrigerant charge) account for nine percent of energy waste among CAC/ASHP installations in the United States, costing homeowners and renters an extra $2.5 billion collectively in utility bills annually (Winkler et al. 2020).

Embedded automated fault detection and diagnostics (AFDD) is a promising solution to decreasing energy waste by making sure the system is installed and operating correctly. Embedded AFDD currently only exists in premium variable speed residential HVAC units but is not used to monitor if the unit is performing efficiently. Additional work needs to be done in high-end units to monitor performance or verify proper installation. Until embedded AFDD is widely available, a near-term solution to improving energy efficiency performance of CACs and ASHPs is to use smart diagnostic tools during installation or maintenance (Butzbaugh et al. 2020). Smart diagnostic tools determine faults in ASHPs and CACs by pairing a suite of digital technician tools with an HVAC diagnostic smartphone or tablet application. These tools provide improved precision and the ability to collect live measurements, identify faults, and suggest corrective actions to fix those faults. Smart diagnostic tools help improve the productivity of HVAC technicians and make it easier for technicians to troubleshoot faults and commission systems – ensuring quality HVAC system installation and maintenance.

STEP mimics the commercial campaigns by serving as a national platform for sharing information and recognizing successes with key stakeholders to accelerate the adoption of a new or underutilized energy efficiency technology. This campaign aims to accelerate the adoption of smart diagnostic tools by providing a one-stop-shop for technical assistance and access to key resources, such as guidance on best practices for implementation of tools, independent testing of available smart diagnostic tools, identification of existing utility incentive programs, case studies, and lessons learned. Key stakeholders for STEP include HVAC contractors (including technicians and installers), weatherization agencies, utilities, energy-efficiency program providers, product developers, trainers, and others. Commercial campaigns have traditionally used national recognition to garner campaign participation. Residential HVAC contractors typically operate locally, so the campaign team is currently investigating whether national recognition is of value to them. The campaign will recognize supporters that have demonstrated impactful support to the campaign by promoting and sharing key resources.

One of the major differences of STEP to the commercial campaigns, is that the primary target for adopting the technology (HVAC contractors) do not directly benefit from the energy savings from use of the technology. Because of this, a series of contractor interviews were conducted to understand the value proposition and barriers to adoption of smart diagnostic tools. From the interviews, the business value created through reduced callbacks, better customer satisfaction, and increased productivity of technicians was found to be the main value proposition. Cost and supplemental training were identified as the main barriers to the tools. Table 5 elucidates the key barriers to adoption and how STEP is addressing those barriers. Because STEP is still in development, the approaches and examples to addressing barriers to adoption are fluid and are subject to change.

Table 5. Barriers Addressed by the STEP Campaign

Barrier	**Campaign Solution**	**STEP Approaches / Examples**
Benefits / business case not well understood	Clearly define the business case for adoption of the solution (product, process, system, etc.) using criteria that is important and relevant for each of the key stakeholders. As a neutral third party, DOE is in a unique position to research and document this information.	**HVAC Contractors:** Developed a case study on contractors that have adopted smart diagnostic tools into their business practices, highlighting the business value creation from adoption of the tools. This case study will be shared with other contractors that have not yet adopted the tools. **Utilities:** Developed a case study on energy efficiency program offerings that required participating contractors to use smart diagnostic tools to perform quality installations and tune-ups of HVAC systems. Participating contractors were trained on smart diagnostic tools and partially reimbursed for tool purchases.
No easy way to distinguish between product offerings	Establish minimum campaign requirements for products/ systems/solutions. Link to more information where possible, making this information easy for campaign participants to find.	**HVAC Contractors:** Offer a table or matrix of tool capabilities as reported by vendors and findings from a tool usability assessment conducted by Pacific Northwest National Laboratory. **Utilities:** Same table developed for contractors will be useful for utilities.
Lack of awareness regarding benefits	Consolidate information on utility program offerings.	**HVAC Contractors:** Offer a list of utility incentives available. **Utilities:** Post information on utility program design, operation, communications, outreach materials and marketing, etc. from utilities that currently offer programs.
Upfront cost is high / hard to find utility program incentives available	Work with utilities and energy efficiency program providers to develop incentive programs.	**HVAC Contractors**: Provide outreach to contractors with information on utility incentives available in their area and will provide information that helps contractors recognize the business case for using smart diagnostic tools, especially in areas where utility incentives are not available. **Utilities**: Conduct outreach to utilities and energy efficiency program providers to offer quality installation and maintenance programs that subsidize or reimburse the cost of smart diagnostic tools.
Too difficult to install and / or commission	Develop and disseminate training resources.	When trained properly on smart diagnostic tools, the tools make quality installation and maintenance quicker and easier for technicians and installers. The campaign will explore barriers in training and work with partners to create necessary resources for training.

Barrier	Campaign Solution	STEP Approaches / Examples
Lack of general awareness of technology / product / solution	Present to key organizations, develop necessary resources, and establish social media presence to bring awareness to the technology.	Drive awareness of the technology via direct outreach to utilities, energy efficiency program providers, weatherization agencies, and contractors; webinars and conferences for contractors, building science, and energy efficiency communities; and the development and curation of resources.
Lack of confidence in real world savings	Consolidate existing and ongoing research and work with utilities to develop a measurement and verification program to collect data on real-world savings.	Tracking existing and ongoing research about smart diagnostic tools. Develop a measurement and verification program with a utility or energy efficiency program provider.

Storm Window and Insulating Panel Campaign (SWIP)

Residential and commercial buildings use nearly 40 quads of primary energy every year, with over 40 percent of that energy being used for heating and cooling. Over half of the residential homes in the United States have inefficient single or double pane clear glass windows, and the thermal gains/losses through these windows account for approximately 25 percent of building HVAC consumption (U.S. Energy Information Administration, 2021). While full double pane window replacements are an effective solution to this issue, low-e storm windows provide an efficient alternative at a fraction of the cost. Low-e storm windows are a good retrofit option for lower-income, multifamily households, households in historic preservation districts, and households working with weatherization programs. First developed to improve the energy performance of both new and replacement windows, low-e coated glass has been widely available on a commercial basis since 2009. Funded by DOE, early development and testing were largely performed by Lawrence Berkeley National Laboratory, and field testing at the Mobile Window Thermal Test facility established that the performance of low-e storm windows was comparable to new low-e window replacements (National Research Council, 2001).

Low-e storm windows, when properly installed on either the outside or inside of a primary window, can greatly improve the thermal efficiency of the window and reduce air infiltration. Residential field studies have shown that the use of low-e storm windows can result in 10 – 30 percent annual HVAC savings. DOE-funded case studies conducted in Atlanta and Philadelphia showed low-e storm windows to reduce air leakage by an average of 17 percent in single family homes and 10 percent in multifamily apartment buildings (Cort, KA, 2013). Modern storm windows are intended to be installed permanently and are designed to be fully operable, removing the need for seasonal installation and regular cleaning. Along with significant HVAC energy savings, low-e storm windows can also provide noise reduction, improved comfort, and aesthetic improvement.

The Attachments Energy Rating Council (AERC) was created by the DOE and the Window Coverings Manufacturers Association to address the need for a comprehensive program to rate, label, and certify the energy performance of window attachments. AERC helps consumers make informed decisions about window attachment products by providing credible and accurate information about their energy performance (Attachments Energy Rating Council, 2019).

SWIP is a national campaign dedicated to accelerating the adoption of low-e storm windows and insulating window panels, delivering both energy savings and comfort in residential and commercial buildings at a fraction of the cost of full window replacement. Through engaging with stakeholders, such as utilities, weatherization programs, manufacturers, and home performance contractors, SWIP aims to increase awareness, visibility, and recognition of the benefits of low-e storm windows and insulating panels. The campaign also serves as a platform for sharing key information, resources, and best practices to help market new programs supporting the application of low-e storm windows and insulating panels. Campaign participants will receive national recognition for demonstrating exemplary performance in encouraging the use of low-e storm windows and insulating panels.

The SWIP Campaign employs the commercial campaign framework but places more emphasis on identifying – and attempting to find solutions for – technical and market barriers, creating awareness around the technology, and providing technical assistance to early adopters. One of the barriers to adoption of low-e storm windows in weatherization programs is that modern low-emissivity storm window technology isn't well characterized or accessible in the energy auditing software that weatherization agencies use to determine if an energy efficiency measure is cost-effective. The SWIP team is engaging with the software developers to better represent the modern storm windows (low-emissivity coating, improved air sealing, etc.) in the energy auditing software. The SWIP team has presented at several conferences and webinars to increase awareness among contractors, weatherization agencies, utilities, and energy efficiency program implementers. The SWIP team has also provided training on this technology for weatherization agencies. For example, SWIP provided a virtual training session for the Indiana Community Action Association (INCAA) and weatherization agencies in Indiana, that included a technical overview of modern storm windows and product demonstrations from ENERGY STAR storm window manufacturers.

Table 6. Barriers Addressed by the SWIP Campaign

Barrier	Campaign Solution	SWIP Approaches / Examples
Benefits / business case not well understood	Clearly define the business case for adoption of the solution (product, process, system, etc.) using criteria important and relevant for each of the key stakeholders. As a neutral, third party, DOE is in a unique position to research and document this information.	Storm window and insulating panel technology and value to homeowners is already well researched. The campaign website serves as a one-stop-shop and consolidates these existing resources.
No easy way to distinguish between product offerings	Establish minimum campaign requirements for products/ systems/solutions. Link to more information where possible, making this information easy for campaign participants to find.	Low-e storm windows can now be ENERGY STAR certified and/or receive energy ratings from the AERC. ENERGY STAR certification or a AERC rating will serve as minimum campaign requirements. The campaign website links to both ENERGY STAR and AERC qualified products lists.
Lack of awareness regarding benefits	Consolidate information on benefits of technology.	Develop resources outlining the benefits of low-e storm windows for utilities, weatherization programs and trainers, contractors, and consumers.
Upfront cost is high / hard to find utility program incentives available	Work with utilities and energy efficiency program providers to develop incentive programs.	Low-e storm windows are a cost-effective technology when compared to full window replacement. The campaign team works with weatherization program administrators and trainers to increase uptake. The campaign engages utilities to provide incentives for low-e storm windows and insulating panels, and the campaign website lists available utility offerings.
Too difficult to install and / or commission	Develop and disseminate training resources.	Low-e storm windows are easy to install by contractors and as a DIY measure by consumers. Consolidate existing resources and develop new resources to outline ease of install.
Lack of general awareness of technology / product / solution	Present to key organizations, develop necessary resources, and establish social media presence to bring awareness to the technology.	Drive awareness of the technology by: direct outreach to utilities, energy efficiency program providers, weatherization agencies, and contractors; webinars and conferences for contractor, building science, and energy efficiency communities; and through the development and curation of a list of resources.

Barrier	Campaign Solution	SWIP Approaches / Examples
Lack of confidence in real world savings	Consolidate resources on real-world savings.	Multiple field studies that demonstrate real-world energy and cost savings exist. Consolidate these on the campaign website.

Conclusions and Future Considerations

The commercial campaign model used by DOE to catalyze the adoption of energy-efficient technologies has been leveraged to design and launch two campaigns focused on residential technologies. STEP focuses on increasing adoption of smart diagnostic tools that help technicians and installers improve the operation of residential HVAC equipment. SWIP focuses on increasing adoption of low-e interior and exterior storm windows to improve building envelope and reduce heating and cooling energy.

In the residential sector the primary beneficiaries of the energy-efficient technologies (homeowners and tenants) are more difficult to reach and provide less energy and carbon savings potential, per residence, than their commercial sector counterparts (building owners and managers), so applying the model for residential technologies required the thoughtful selection of key partners to maximize the impact of campaign efforts. Key partners for the residential campaigns include contractor training and trade organizations and utilities and energy efficiency program providers. Partnering with contractor training and trade organizations enables the campaigns to reach many contractors that interface with homeowners and tenants directly. Partnering with utilities and energy efficiency program providers allow the campaigns to help develop local incentive programs to stimulate adoption of the technologies and to provide awareness and education about the energy-efficient technologies to their customers. In applying the commercial campaign model, special care was taken to understand the value proposition for adopting, or advocating for, the energy-efficient technology for all campaign partners. Because the residential campaigns are ongoing, best practices and lessons learned from the commercial campaigns will continue to be leveraged, and the commercial campaign model will continue to be translated to suit the needs of the residential sector.

Although DOE campaigns target the United States, the models demonstrated in this paper can be applied internationally to encourage voluntary adoption of promising technologies. Through the proper identification and engagement of partners, campaigns can serve as a source of information for adopters of technology, provide technical support, and document successful projects that serve as proof of the benefits of a technology for peer building owners. Efforts to better share the resources from campaigns internationally and to collaborate with international partners in the development of international campaigns can help meet global carbon reduction goals through energy efficiency.

Campaigns aim to catalyze the adoption of technologies at-scale by leveraging exemplary projects that have already demonstrated successful implementation. To support the broader needs of the commercial and residential building sector and support the future broad-scale adoption of a technology, DOE programs—such as technology campaigns—need to address the particular challenges to adoption faced by underserved communities in their program design. Current efforts in the Integrated Lighting Campaign, for example, include a concerted effort to identify projects in underserved communities and to recognize and highlight exemplary projects demonstrating what is possible with limited resources or through innovative financing options. In fact, innovative maintenance, operation, and financing service models is covered in a recognition category in the second year of the Integrated Lighting Campaign to highlight transformational business models. Furthermore, the Integrated Lighting Campaign developed a recognition category in its second year to recognize supporters who champion energy justice, diversity, equity, and inclusion through their programs. Current efforts for the SWIP and STEP campaigns include targeted outreach and engagement with weatherization agencies that serve income-qualified households. Like the ILC, the SWIP and STEP campaign teams are investigating how recognition can be used to highlight campaign partners who champion energy justice, diversity, equity, and inclusion through their programs.

On behalf of DOE, Pacific Northwest National Laboratory is leading the development of an energy equity and justice advisory panel to advise programs on how to better support the equitable development, deployment, and adoption of clean energy technologies and practices, as well as to support a collaborative inter-laboratory approach to addressing issues of energy equity and energy justice. This effort aims to inform how technology campaigns develop outreach and communications materials, as well as informing communications approaches or channels to better serve underserved communities. Another aim is to research and refine definitions and metrics around equity in commercial spaces to inform technology campaigns moving forward.

These efforts will also hopefully uncover potential project partners who we may not traditionally reach through existing channels. Additional research efforts underway include a pilot study in the Phoenix, AZ and Atlanta, Georgia metropolitan areas to characterize how small/light commercial building owners and operators go about making energy choices. This pilot will focus on revealing how these building owners and operators manage energy use, make renovations, and prioritize existing challenges in terms of access to key resources (knowledge, capital, and materials) to succeed in their business environment.

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Data collection to support energy efficiency finance in the building sector

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Abstract

The lack of empirical evidence and statistical data on the actual energy and costs savings achieved is today one of the key challenges to overcome in order to increase energy efficiency investments. Data is still hard to access because it is decentralized and in different formats. Consequently, only a small part of this can be used to produce reliable empirical evidence on the performance of the energy efficiency investment.

The goal of EN-TRACK H2020 is to create a one-stop shop platform with standardized data related to the energy efficiency performance of the public and private building stock. The platform will e.g., allow for benchmarking of the financial performance of specific energy efficiency measures (EEM). The user can analyse trends in financial performance of EEM investments by defining (ranges of) financial parameters and seeing distributions and standard deviations of various EEM types. Several filter criteria (location, building type and use, etc.) will allow a more customized analysis, ensuring a minimum number of projects to be included in the sample. The tools and platform developed through the EN-TRACK project will be based on enabling interoperability with most currently active databases and tools (e.g., DEEP and eQuad platforms) that will support more efficient building refurbishment decision making processes, putting it into practice with the financial sector. During the presentation, the speaker will present the first development of the project and practical demonstration of the platform.

Background and Motivations

The lack of statistical data on the actual energy and costs savings achieved through energy efficiency investments (EEI) has been one of the principal challenges of increasing energy efficiency investments. This can be attributed to several underlying factors that have facilitated the idealisation and incentivised the creation of the EN-TRACK platform.

Advancement in recent technology, market and policy drivers have resulted in rapid increase in the generation of building and energy data (including retrofit and O&M costs). However, accessing aggregating, sharing, and utilizing this data is relatively hard as it is being housed in many decentralized databases, and in different formats[245]. Consequently, only a small part of this information can be analysed, compared, and benchmarked to produce reliable empirical evidence on the performance of the EEI necessary to decision-makers and investors.

The Energy Efficiency Financial Institutions Group (EEFIG) report identifies the key policy and market-led approach to increasing the supply of EEI as the creation of an EU open-source building performance databases and standardised processes for collection, organisation, and open access for data on the existing building stock. This is in line with the Eurostat and Inspire Directive standards and has proven very effective in the U.S. EEFIG points out that an "operational" database supporting portfolio benchmarking analysis and built on increasingly available data from smart-metering and other sources[246] has been a request from many financial institutions and industry stakeholders. There are some databases in Europe, however they are still local and limited in functionality and interoperability.

Large building portfolio owners such as Public Authorities and other large building owners have available the necessary energy and financial information about their buildings to evaluate EEI performance. This information however is dispersed and managed in separate departments (O&M, Accounts, etc.) or external providers and data gathering is difficult. Furthermore, building owners have little incentive to share data due to high effort, have low awareness of its value and have concerns about security and privacy.

[245] Building Energy Data Exchange Specification Scoping Report. Stakeholder & Technology Review, 2013. https://www.energy.gov/eere/buildings/downloads/building-energy-data-exchange-specification-scoping-report

[246] e.g., EPISCOPE. (2014). IEE Project EPISCOPE [Website]. Retrieved from: www.episcope.eu

Public buildings represent about 12% by area of the EU building stock[247] and enabling data collection there is a key issue as they centralise information and can perceive both the benefits (improved building retrofitting rate, energy and cost savings, productivity, and value improvements) as well as for wide societal improvements such as improved decision-making capacity, energy policy and public awareness.

An existing gap in the available empirical data has resulted in a lack of fully representative set of data even in the most current databases (including DEEP[248]) as there is insufficient data in certain building typologies. Detailed building simulations, building certification or reliable engineering estimations can help in filling this gap by augmenting and answering questions that are out of scope of empirical data[249]. This data needs to be wisely combined and analysed to allow deeper insights while keeping track and considering the source, level of credibility and uncertainty of the data in the databases in order to reduce the risk in the decisions based on it.

A variety of tool are currently available that offer features and complementary services supporting decision making for EEI. However, due to lack of comparability and interoperability with other tools, it is difficult for them to achieve sufficient critical mass of users for successful commercial uptake. Open-source software, common frameworks, standards, and interoperability among tools have proven to stimulate tremendous advances in areas such as, big data solutions. [250] [251]

With these various shortcomings in mind, the EN-TRACK consortium set up to create EN-TRACK with the aim of enabling an interoperable ecosystem of data and tools in the area of building energy efficiency supporting the technical and financial decision making in refurbishment of the existing building stock and to prove its utility by putting it into practice, gaining traction with the financial sector and really making it into mainstream activity.

EN-TRACK Bridging the Gap

Using proven existing infrastructure developed by CIMNE (SHERPA[252] & EDI-Net [253] platform) EN-TRACK builds on this aiming to enable massive data gathering to support better decision-making (that is; more informed, more transparent, and faster) to make data comparable and interoperable with other existing databases, and to contribute to the de-risking of investments in energy efficiency in buildings by analysing this data and offering relevant results to key stakeholders. Moreover, EN-TRACK aims to make this in a way that is self-sustaining so that the results will prosper and grow after completion of the EU project. EN-TRACK will achieve this by:

- Providing an open-source big data platform capable to acquire and harmonise data from multiple sources on the base of internal standardised description of building data and energy efficiency measures (EEM), and standardised data-driven approach to evaluation of EEI performance.

- Attracting large public building owners (governmental, regional, municipal) in continuous collection and sharing of building data by offering them user-friendly web application for accessing robust benchmarked data and information on types of energy investment and by backing this up with an extensive database and additional services that will attract more data as it grows.

- Enabling interoperability with most currently active databases and tools (DEEP, eQuad, EnerInvest, etc.) and moving toward compliance with other relevant initiatives such as BEDES (Building Energy Data Exchange Specification), through open source and vendor-neutral technology, paving the way to an ecosystem of products and tools able to exchange data and offer complementary services without ambiguity and at low transactional costs.

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[247] Ecofys, Ecorys & Bio Intelligence Service. (2010). Study to Support the Impact Assessment for the EU Energy Saving Action Plan.
[248] De-Resking Energy Efficiency Platform (DEEP), https://deep.eefig.eu
[249] Avoiding epistemological silos and empirical elephants in OM: How to combine empirical and simulation methods? Aravind Chandrasekaran, Kevin Linderman, Fabian J.Stingc, Journal of Operations Management, Vol. 63, November 2018, Pages 1-5
[250] Apache Hadoop ecosystem, https://hadoop.apache.org
[251] Open Data Platform initiative (ODPi), https://www.odpi.org
[252] SHERPA - SHared knowledge for Energy Renovation in buildings by Public Administrations , https://sherpa.interreg-med.eu
[253] EDI-Net – The Energy Data Innovation Network, https://www.edi-net.eu/

- This represents a big step towards a ratings system that will make a significant contribution to moving energy efficiency investments towards the mainstream activity of the financial sector.
- EN-TRACK will also develop and test various business models and value allocation arrangements among the stakeholders in order to make the action self-sustainable and adaptable in the long term.

Objectives

With the primary aims EN-TRACK has set seven specific objectives as follows:

1. **To develop/adapt a big data platform for gathering, processing, and benchmarking large-scale data on actual financial performance of energy efficiency investments**. The platform will enable an operational database and web application offering services for performance tracking and benchmarking of building portfolios that will support more informed, more transparent, and faster decision making and, thus, de-risking of investments in energy efficiency in buildings.

2. **To Implement the Building Energy Data Exchange Specification (BEDES) data model** in order to make data from different sources comparable and suitable for the platform. Data sources will include metered energy consumption, EEM and verified real investment data, energy audit and/or simulation info as well as information on the drivers for investment and non-energy benefits. The standard BEDES data description will be implemented as internal reference for data harmonisation and for enabling interoperability with external databases and tools.

3. **To implement databases, analytics and benchmarking enabling data-driven investment risk assessment.** EN-TRACK will enable collection of empirical data on energy efficiency investment performance and will combine it with additional knowledge and simulation data in order to fill any information gaps. Data will be stored in databases keeping track of each data source, its level of credibility and the associated data uncertainty. Analytics will allow sensitivity analysis for risk assessment evaluations from different angles/perspectives thus reducing the decision risk.

4. **To make the platform interoperable and complementary to the EEFIG-DEEP, eQuad[254] and EnerInvest[255] platforms.** EN-TRACK will adopt DEEP specifications, data model and EEM definitions to ensure compatibility; develop Application Programming Interfaces (API) for data exchange with DEEP, eQuad and EnerInvest; aggregate buildings and EEM into investment criteria portfolios; collect complementary information about investment decision rationale and the non-energy benefits such as comfort and O&M; develop a standard and objective procedure for monitoring and validation of resultant energy and cost savings based on continuous data collection and evaluation; and detect any degradation of the EEM effect over time.

5. **To promote and incentivise the widespread adoption of the platform**, making the data reporting attractive by considering user requirements, improving user experience and providing additional services (such as, energy management, energy benchmarking, financial performance benchmarking of energy efficiency measures (EEM), suggestions and recommendations) to encourage use of the platform. EN-TRACK will develop extensive communication, dissemination and exploitation activities and using the project partners' and supporting organisations' existing networks and platforms as nexus to wide user audience
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6. **To provide capacity building for investors and building owners** by means of workshops and targeted communication, dissemination and exploitation activities during the project. The activities will

[254] eQuad platform: A bridge to Sustainable Energy Efficiency Financing. https://www.eu.jouleassets.com/about-equad
[255] EnerInvest: Spanish Sustainable Energy Financing Platform, https://www.enerinvest.es/en/

focus principally on the use of the platform and how it can be used for supporting decision-making and de-risking of energy efficiency investments.

7. **To make the platform economically sustainable** by developing and testing various value-sharing arrangements and business models (x10 expansion in 5 years post-project anticipated). Mechanisms to cover platform maintenance costs after the project include: costs assumed by the financial institutions (driver: to reduce investment risks); a subscription fee from building owners or ESCOs (driver: receive services and reduce investments costs or ease the approval of financing); a marketplace for investors and service companies; a mixed model for cost sharing.

Progress thus far

In the first year of the EN-TRACK project, efforts have been heavily focused on identifying a methodology for ensuring ease of data uptake, aligning with the currently active databases for massive data gathering and exchange, and ensuring a standardized way of accessing this data from stakeholders. This stakeholder engagement has as well been aimed at understanding the needs of the future users of the platform, and ensuring that the final platform will be a tool that is of good use for the market. This has happened largely through quarterly events called the (1) Building Owners Forum and (2) Financial Institutions Forum. These forums are hosted on a quarterly basis with topics and questions that are needed for the platform development and ensuring that EN-TRACK does not lose sight of the needs of the stakeholder, or miss something crucial in the process of development. These events also provide an opportunity for hopefully creating future users.

With the methodologies and data requirements confirmed in the first year, development of the platform has been advancing in paralell, and a first iteration of the platform has been created in mockups (see figure 1). The full development of the platform along with integration with other existing platforms (such as the eQuad platform) is now underway and the goal is to be able to present a first complete version of the platform at the EEDAL conference June 2022.

In short, the following has been been focus of year one:

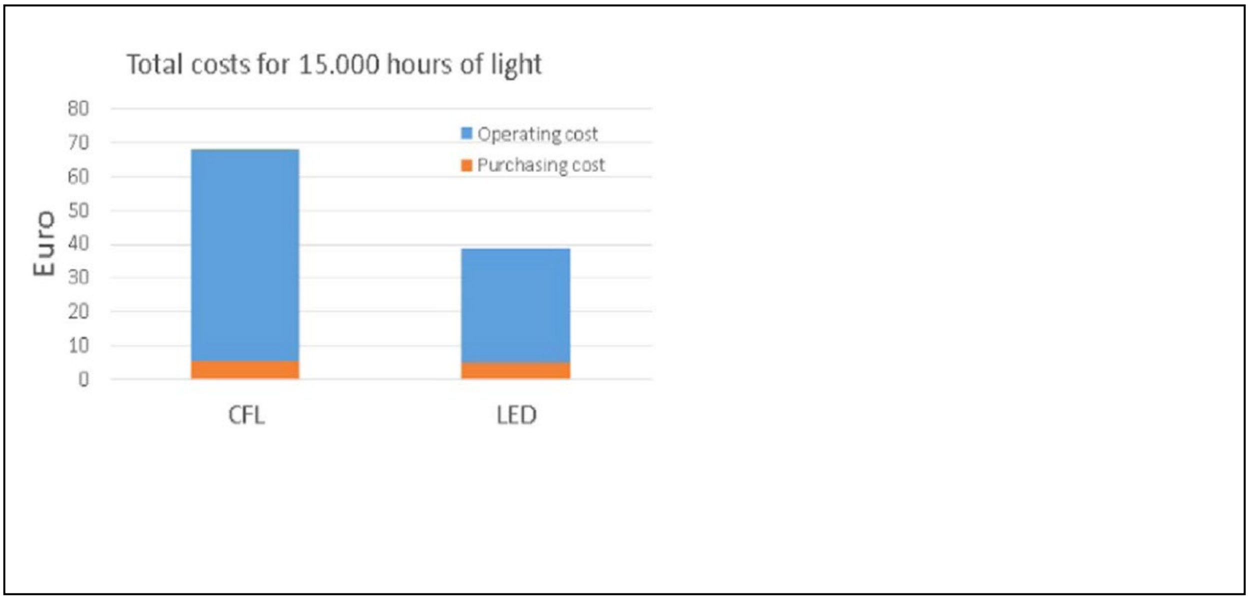
- Overall requirements and data model
- Data sources subsets and collection procedures
- Data management
- Dissemination and communication, stakeholder engagement
- Specifications for calculations of indicators and benchmarking

Based on the gathered feedback through above activities, the following platform functionalities were identified as priorities for the financial sector:

- Benchmark and compare the energy performance of buildings before and after measures implementation.
- Benchmark and compare the performance of specific energy efficiency measures or technologies in terms of energy savings.
- Benchmark and compare the performance of specific energy efficiency measures or technologies in terms of return on investment (ROI).
- Track the performance of projects funded by grants or programs.
- Analyse trends in the financial performance of investments in energy efficiency measures.
- Sensitivity analysis of risks related to energy efficiency measures.
- Recommending energy efficiency measures.

- The platform must be easy/intuitive to use to differentiate it from the cumbersome and complex platforms that currently exist.

Figure 34. EN-TRACK landing page



Impact

Through EN-TRACK financial institutions (FI) will be impacted by way of enabling interoperability, data exchange and joint promotion with existing tools and platforms already having established networks of financial institutions. Through direct communication, dissemination, and training during the course of the project and by networking through advisory board members

Building owning public authorities (PA) and ESCOs will be impacted by way of engaging existing users of SHERPA/EDI-Net, engaging users of the connected tools, platforms and municipalities in Europe and through direct communication, dissemination and networking during the course of the project. EN-TRACK will reach up to 104 (building owners and ESCOs) and the potential volume of investment in their building stock will be up to 442 M€. During the 5 years after the project is expected to reach 1,039 stakeholders triggering potential investments of 6,390 M€.

A standard, vendor neutral, platform and architecture framework for interoperable tools and applications will develop by EN-TRACK supporting; collection, alignment, and analysis of data from different sources including audit, interval data, real estate data, benchmarking of EEM and EEI, energy efficiency investment (EEI) decision-making, efficiency program evaluation and building performance tracking

In terms of offering data harmonisation, analysis and benchmarking EN-TRACK platform will offer significant improvements based on standardised descriptions with standardisation aspects of the platform including; BEDES – data description, harmonisation and alignment from different sources, ICP – standard project description, evaluation and risk assessment, IPMVP – standard evaluation of savings, impact of EEM, and full compatibility and data exchange with existing solutions (DEEP, eQuad, EnerInvest)

EN-TRACK will not directly lead to higher allocation of institutional investments but does address and propose a solution for one of the key barriers in the securitization of EE assets: a (pan-European) standard for monitoring, reporting, and communicating EE investment performance. While this solution's direct contribution to the growth of a secondary market is impossible to quantify, EN-TRACK will involve several (institutional) investors who will provide their views and feedback on the usefulness of the proposed standard (via the AB for example). The new standard will build on BEDES and offer further integration with existing solutions currently active in Europe (DEEP, EnerInvest, eQuad, etc.) offering operational benefits such as improved efficiency, time saving and improved access to finance.

Through EN-TRACK energy savings will be triggered firstly by the investments facilitated this can be considered in two categories: those produced directly by the pilot validation actions with in the project, those produced by the investment triggered by the project for the ESCO companies. Secondly due to the services provided through the web application resulting in improved building energy management.

Increase in sustainable energy investments triggered by the project this is closely related to the previous described impact with our conservative estimate being that during the project EN-TRACK will trigger an additional 1% of the project worth processed in the EN-TRACK ecosystem from eQuad, EnerInvest and DEEP

The impacts in terms of primary energy savings will have a direct effect in terms of GHG emissions reductions, calculated as 17,512 tCO_2eq/year within the project and ten times more within the five years following the project.

There are several areas over which the project will exert wide and transformational impact/effect due to its vendor-neutral, standard and inclusive approach permitting to connect and potentiate the use of other external tools, aimed at growing eco-system of complementary services and tools.

- **Policy empowering:** decision making enhancement (enabling evidence-based decisions considering national, regional, and local specifics of building stock); energy policy de-risking (data-driven approach considering the cost and effect of the policy decisions); paving the way for regulatory changes (facilitating the adoption of voluntary or mandatory energy data disclosure schemes for e.g., PA, municipalities, …).

- **Technological development:** enabling interoperability of complementary tools supporting the increase of EEI; open software scalable big data storage and analytics platform, open database ready to use by implementing energy data disclosure schemes; state of art data protection and anonymization procedures & access to data at different levels.

- **Sustainable development:** progressing towards more a more circular local economy in Europe by reducing energy demand, investing in the local economy, generating local employment, and improving comfort, quality of life, well-being etc.

The project contemplates a comprehensive view of the energy investment landscape, and the figure below offers an overview where EN-TRACK will make an impact. All these areas in the landscape are inter-related.

Figure 2. EN-TRACK Impact Illustration

	Group 1 ("watts")	Group 2 ("lifetime energy operating costs")	Group 3 ("annual energy operating costs")
Energy consumption/energy operating costs	60 W	€180	€18
	115 W	€340	€34
	170 W	€500	€50
	225 W	€660	€66
WTP:	480 €	640 €	350 €

Conclusion

EN-TRACK will not directly lead to higher allocation of institutional investments but does address and propose a solution for one of the key barriers in the securitization of EE assets: a (pan-European) standard for monitoring, reporting, and communicating EE investment performance. Current findings show, that to overcome this barrier, an increasing importance lies in the business model adapted for the EN-TRACK platform. Despite all stakeholders communicating through all stakeholder activities that the platform is a valuable tool for their processes and objectives, selling the platform at the end of the project duration as a subscription product directly to the end user looks unlikely at current due to low willingness to pay. Therefore to incentivize widespread usage and ensuring the financial sustainability of the platform long-term, an increased activity in the last year of the project will be to establish partnerships and integrations with other platforms (such as eQuad and others) to open new sources of revenue and added value in terms of data access and user uptake. Some financial agreements, to ensure the sustainability of the platform, are already in place and will enable further development and expansion of the platform post project duration.

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Eight years measurement data of a deep renovated residential building

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Abstract

A typical residential building from 1937 located near Wuerzburg, Germany undergone deep energy renovation in 2013. Roof, façade and basement ceiling were highly insulated and thermal bridges were minimized. Existing windows were replaced with triple glazing and wood-aluminium frames windows. A balanced ventilation system with integrated air-to-water heat pump was installed together with an 8 kW PV system (roof-integrated). The ventilation ducts were integrated into the existing chimneys. The residential appliances (white goods) (refrigerator, washing machine, dishwasher) were installed or replaced by A+++ equipment. The cooking equipment was replaced by induction device. The existing lighting fittings were replaced with LED lighting products.

The key performance indicators were measured over a period of eight years (2014-2021). Energy production, energy use, energy costs, self-consumption and exported electricity to the grid were monitored. The results show variations in performance indicators. The self-consumption varied between 16.9% and 25% while the annual energy costs varied between 387 EUR (2018) and 792 Euros (2021) (193%) which has implications for economic evaluation. The robustness of the key performance indicators is discussed and recommendations for designers and planners as well as prosumers are given.

Introduction

Residential use of energy is responsible for 28% of EU energy consumption [1]. The barriers to consumer-related energy saving have been known for more than 30 years but are still present, in particular split incentives (e.g., tenants vs. landlords), lack of information, high initial investment in energy-efficient measures and equipment and energy users' behaviors [2].

Likewise, while awareness of the existence of renewable energies has improved considerably in the last years, there is still a lack of understanding of how to use and optimize them in practice.

As of 2021, all new buildings have to be Nearly-Zero Energy Buildings (NZEBs) as required by the EPBD [3]. In addition, renovating both public and private buildings has been identified as an essential action in the European Green Deal to drive energy efficiency in the sector and deliver on objectives [4].

There are many approaches to this goal and several pilot buildings have been built and extensively measured. The theoretical approach in the NZEB concept is typically based on two pillars. The first one refers to energy saving measures to reduce the energy needs. The second pillar is represented by the consumption of renewable energy produced on-site (or nearby) [5;6]. Both measures have been applied in this case.

A residential building from 1937 located near Wuerzburg in Germany was deep retrofitted in 2013 (Figure 1). The project received funding from the German Bank for Rebuilding (KfW) in the class kfW55 which uses 55% of the allowed energy budget frame defined in the existing German building code (EneV) [7;8]. More ambitious levels (e.g., KfW40 or any type of zero energy buildings) do not exist for refurbishments, only for new constructions. However, there were, additional funding schemes for heating systems and feed-in tariff (FIT) for photovoltaics (PV) [9]. Today, the funding schemes as well as FIT are under revision [10].

Figure 1. Building view (left photo - before renovation; right photo - after renovation)

Building envelope

Roof, façade, and the basement ceiling were highly insulated and thermal bridges were minimized. The existing windows were replaced with three glazed windows with wood-aluminum frames.

Energy supply for heating, DHW and ventilation

A compact unit for balanced ventilation with integrated air-to-water heat pump was installed. The exhaust air is used as heat source. An underfloor heating system was installed in the kitchen. The electricity used for heating and DHW is monitored in a separate meter. The ventilation system delivers 220m^3/h to all the rooms (except storage room on 2nd floor approximately 35m^2) with a supply and extract fan (with dampers). The compact unit also includes a cross-plate heat exchanger with 85% thermal efficiency. The ventilation ducts were integrated into the existing chimneys. Energy use of the compact unit was monitored separately and is not part of this analysis.

Appliances

The residential appliances (white goods) (-refrigerator, washing machine, dishwasher) were installed or replaced with highly energy efficient (A+++) equipment. The existing cooking equipment was replaced with an induction device and the old lighting fittings were replaced with LED bulbs.

Figure 2. PV system and layout. south-west orientation (left photo of the south-west facade; right module layout with monitoring figures for each module

A 7.95 kW roof-integrated PV system with a south-west orientation and 50°angle was installed. The PV system consists of 32 modules with 165 W each (see Figure 2). The inverter controls each module separately, ensuring minimized shading effects from the 'Gaube'. No battery storage is installed in the building. The electricity produced by the PV system is primarily used to cover the energy needs of the building and the surplus is exported to the grid. Since FIT was fixed in October 2013, a rate of 0.1454 €/kWh was given by the local energy provider ('Stadtwerke') for buying while demanding electricity costs of 32 € cent/kWh (including fix costs). The potential for saving energy costs should encourage self-consumption.

Objectives

This case of a prosumer model without considering heating energy consumption is not very often in focus of analysis. In addition, eight years of measurement data is available that can be used to examine the robustness of new performance indicators related to prosumer models. This project represents a comprehensive retrofitting towards prosumer model. Energy consumption and production as well as usage patterns and load profiles were monitored over a period of eight years. PV electricity production, electricity use, and export of electricity to the grid was monitored. This provides valuable insight into the concept of buildings with prosumer models [10].

Method

A typical residential building from 1937 located near Wuerzburg in Germany, was monitored. For that, the following Key Performance Indicators (KPIs) from 2014 to 2021 are chosen: energy production, energy use, energy costs, self-consumption and exported electricity to the grid were monitored. In addition, KPIs describing the self-consumption were also monitored [11]:

Self-consumption: $SC = E_{oc} / E_{PV}$ (1)

Level of autarchy: $LA = E_{CO} / E_{total}$ (2)

Load matching: $$f_{load} = \frac{1}{N} \cdot \sum_{year} \min\left[1, \frac{g(t)}{l(t)}\right] \quad (3)$$

Grid interaction: $$f_{grid} = STD\left(\frac{ne(t)}{max(|ne(t)|)}\right) \quad (4)$$

where

E_{CO} is own consumption (household)

E_{PV} is the electricity produced by PV system

E_{total} is the total energy use of household

g(t) is the energy generation at each time step

l(t) is the energy load at each time step

N is the number of samples in the evaluation period

ne(t) is the net export at each time step

Results

The monitored key performance indicators are divided into the following categories:

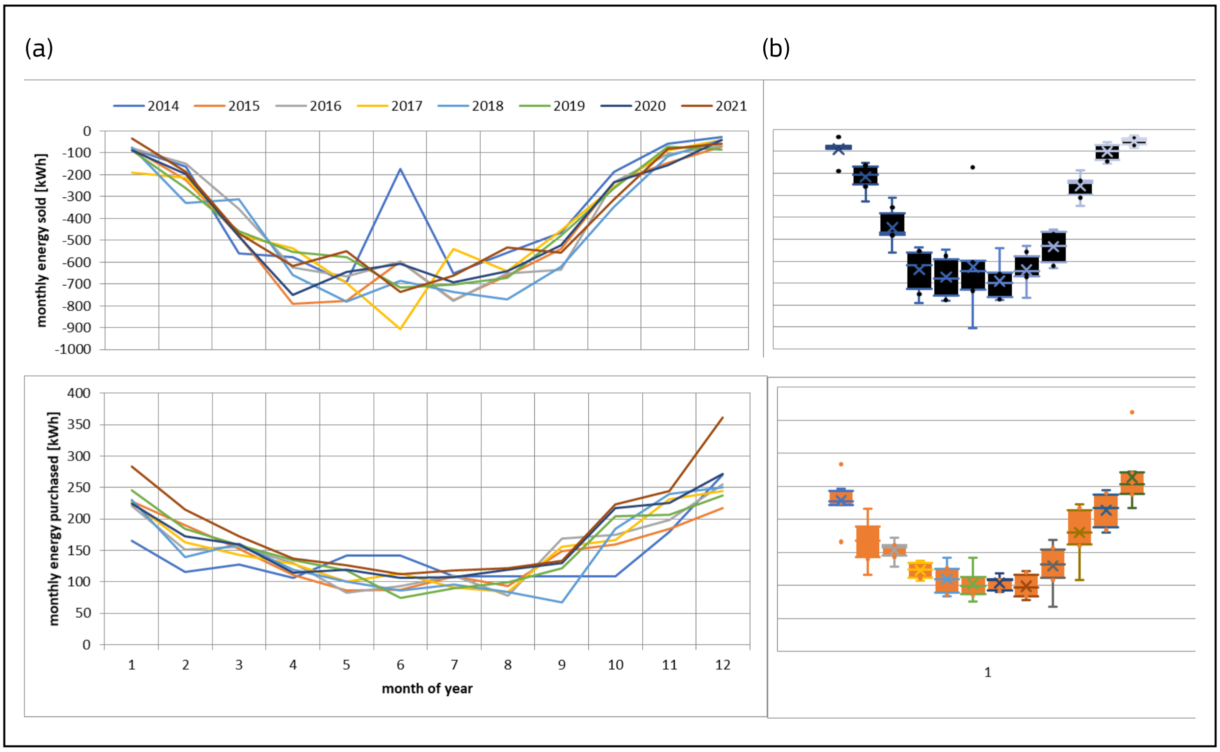
- Electricity use
- Electricity produced by PV
- Electricity self-consumed
- Electricity costs

Electricity use

The purchased electricity was monitored separately for the heat pump and the remaining circuit.

Figure 3 shows the monthly electricity sold to the energy supply company (top figure) and the monthly purchased electricity from the grid (bottom figure). In Figure 3a (left), the monthly electricity (sold and purchased) is shown, while in Figure 3b (right), the monthly spread is shown for all eight years of measurement period.

Figure 3. Monitored electricity: sold (top) and purchased (bottom)



The box and whiskers charts, which give the median values as well as the middle 50% figures in the boxes. while one whisker on either side of the box represents the top 25% and bottom 25% of the figures.

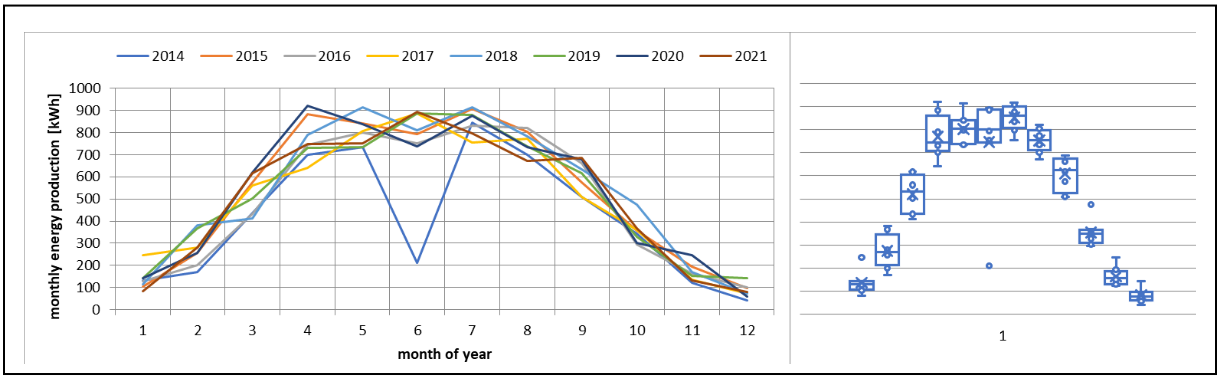
It can be seen that electricity sold to the energy supply company is highest during summer. July is the month with the highest median value (691 kWh/month), followed by May (672 kWh/month) and August (640 kWh/month). Electricity purchased was lowest during summer months and highest during winter months. December is the month with the highest median value (263 kWh/month) followed by January (228 kWh/month) and November (213 kWh/month).

Electricity production

Figure 4 shows electricity production from PVs. Electricity production varies over the year with maximum yields in summer months and minimal yields in winter months. The largest (median) values were monitored in July (851 kWh/month), followed by May (802 kWh/month). The lowest (median) values were monitored in December (82 kWh/month), followed by January (136 kWh/month).

It can be seen that in June 2014 there was a significant drop. This is due to a failure of one of the two inverters. To get the inverter repaired took almost 3 weeks during which the electricity produced could not be exported into the grid.

Figure 4. Monthly PV system electricity production



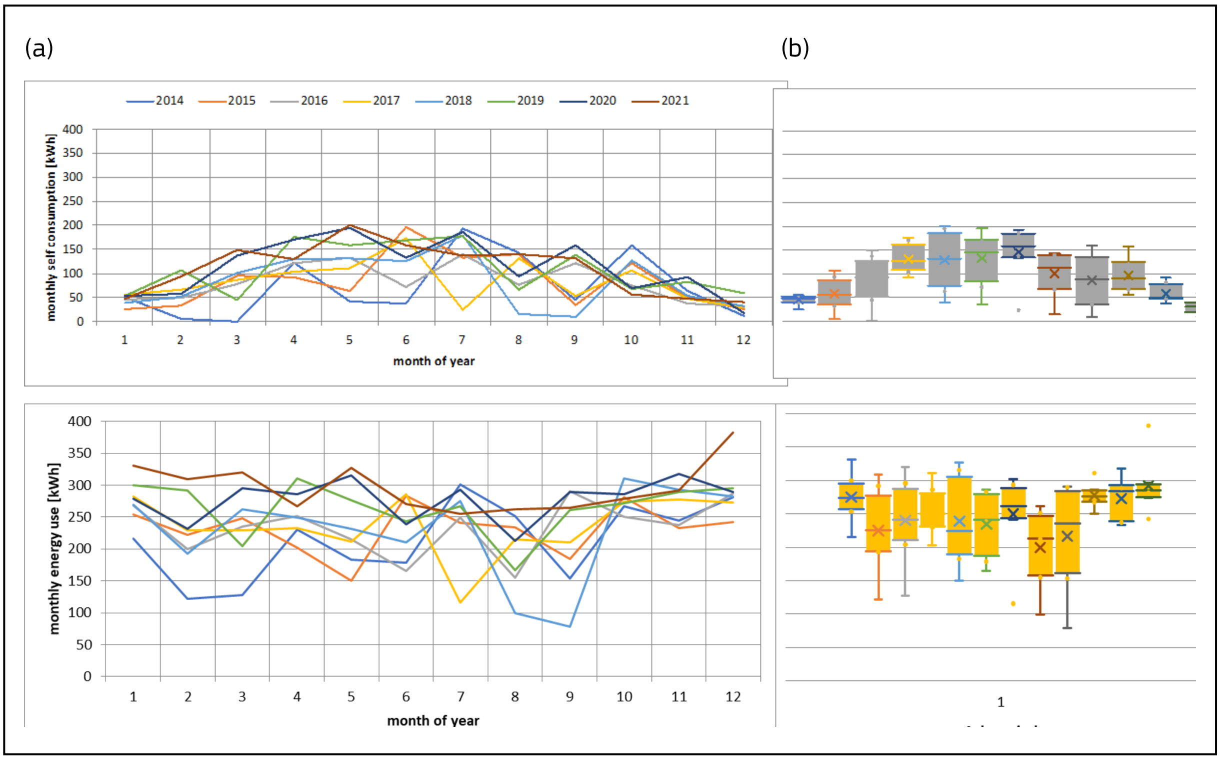
A greater variation in the electricity production is observed during summer months (boxes indicate 50% of the range) e.g., 160 kWh in April (between 700 and 860 kWh). The variations are largely due to solar radiation. So far, analyses of radiation were not performed but it is recommended for further studies.

Self-consumption

The results show variations in self-consumption. While self-consumption was higher during summer months in absolute figures, it dropped during winter months (see Figure 5a (left)). The highest (median) self-consumption was monitored for July (137 kWh/month). Self-consumption was influenced by the electricity use variation in the household (Figure 5; below). Here, the highest (median) electricity consumption was monitored in December (291 kWh/month), while the lowest energy consumption was monitored for August (200 kWh/month).

Figure 5b (right) shows the monthly variations over the monitored period. The self-consumption shows greater variation during summer months (boxes which indicate 50% of the self-consumption figures) e.g., 111 kWh in May (between 75 and 186 kWh), while during winter months, it varies less, e.g., between 18 and 32 kWh/month in December (with 59 kWh/month identified as an outlier).

Figure 5. Monitored electricity self-consumption (top) and electricity use (for household) (bottom)



The other key performance indicators are shown in Table 1. Self-consumption varies between 16.9% (2015) and 25% (2021). The level of autarchy varies between 34.1% (2014) and 45.4% (2020). Load matching varies between 64.1% (2014) and 67.5% (2017). Grid interaction varies between 28.4% (2020) and 37.1% (2019).

Table 1. Key performance indicators self-consumption, level of autarky, load matching and grid interaction results for 2014 to 2021

	2014	2015	2016	2017	2018	2019	2020	2021
Self-consumption (%)	18.0	16.9	18.9	17.0	16.9	21.3	22.2	25.0
level of autarky (%)	34.1	36.4	35.1	34.9	36.2	44.4	45.4	43.7
load matching (%)	64.1	67.2	64.3	67.5	66.5	66.5	66.6	66.3
grid interaction (%)	33.1	31.2	29.3	32.1	37.6	34.1	28.4	30.9

Electricity costs

There are several energy tariffs for different electricity streams as summarized in Table 2. At least three different tariffs have been considered:

- Electricity purchased for household
- Electricity purchased for heat pump (only considered for total costs in Figure 5)
- PV electricity self-consumed
- PV electricity sold to grid

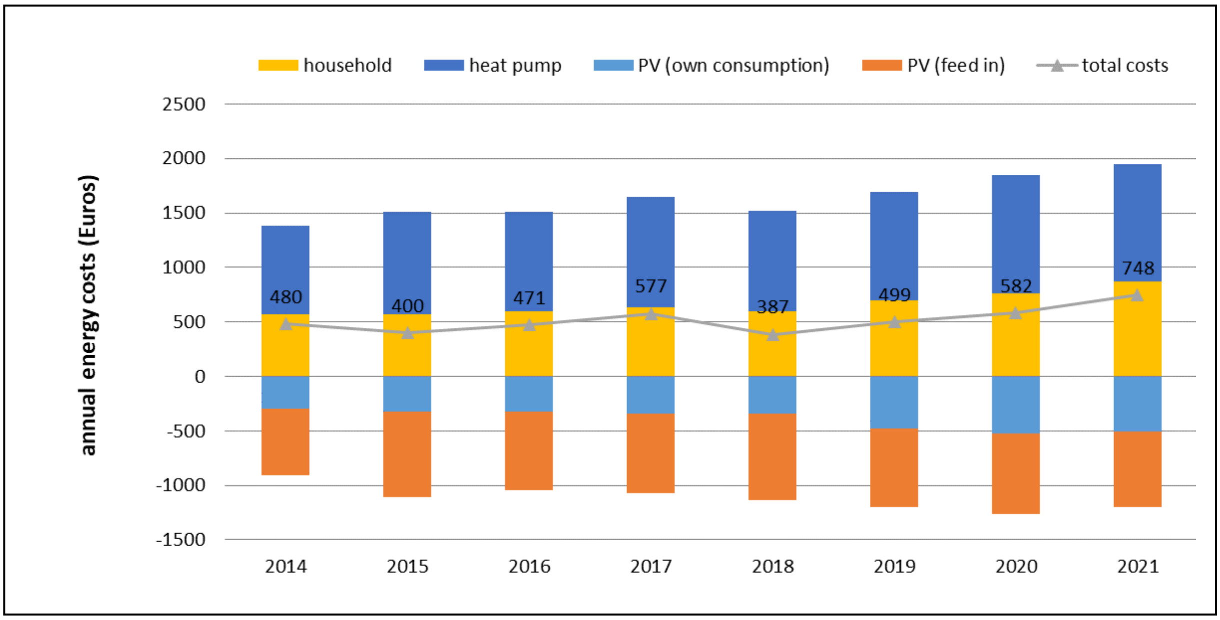
It can be seen that electricity tariff for household electricity ranges between 0.34 and 0.39 €/kWh. The energy price is including working tariff, fixed fees (transfer pricing and fixed performance price) and all taxes which are included in the bill. For the electricity of the self-consumed electricity from PV production only the working tariff plus taxes (electricity tax and value added tax) have been considered. For the electricity supply a special 'heat-pump' tariff was chosen (HT: 0.2818 €/kWh; LT: 0.2053 €/kWh). Table 2 reports the average tariffs.

Table 2. Electricity prices for electricity purchased (and self-consumption) and electricity sold to the grid

Price [€/kWh]	2014	2015	2016	207	2018	2019	2020	2021
Household	0.340	0.323	0.327	0.341	0.341	0.370	0.386	0.386
Heat pump	0.238	0.221	0.226	0.232	0.232	0.245	0.260	0.260
PV electricity self-consumed	0.274	0.264	0.268	0.282	0.285	0.306	0.332	0.332
PV electricity sold to grid	0.1454	0.1454	0.1454	0.1454	0.1454	0.1454	0.1454	0.1454

Figure 6 summarizes annual electricity costs for household, self-consumption and electricity use (for household). For comparison reasons, the figure also includes energy costs for heat pump. It can be seen that total energy costs (grey) as well as household energy costs (yellow) have increased since 2018.

Figure 6. Annual electricity costs for household, self-consumption and electricity use (for household) (for comparison also including energy costs for heat pump)



The revenue from PV electricity production (counted as negative) consists of revenue from selling electricity (orange) to the energy provider plus the revenue from saved electricity costs from self-consumption (lighter blue).

The total energy costs were 480 € in 2014 and have increased (except in 2018 and 2019) to 748 € in 2021. This is an increase of 156% (2021 compared to 2014). It should be noted that energy costs amounted to 1415 € before renovation. There are still energy cost savings due to the renovation measures, but the increase of energy costs influences the payback calculations of the renovation measures considerably.

Discussion

The PV system exporting energy into the grid and delivering electricity to the household is one standard prosumer model. New performance indicators of grid interaction, level of autarchy, self-consumption and load matching are varying over the monitored period. However, they provide relatively robust characterization of the system.

Economic performance of prosumer models requires at least two sets of data.

First, the energy use must be monitored. In this case, the electricity used for heating and DHW was monitored separately and is not part of this analysis. However, if the electricity produced could also be used to power the heat pump, different self-consumption figures could be achieved.

The electricity exported into the grid is monitored (for obvious tariffs reasons). However, the energy produced by the PV system is also monitored. The difference between the energy produced and the exported energy gives an indication of the renewable energy consumed by the building. When adding the self-consumed component of the PV electricity production, the household energy use can be derived. Further energy measurement could help to better quantify the household energy use and to maximize the potential for energy savings. Here, the time resolution of the measurement as well as the balances will influence the self-consumption figures. This could also be estimated in dedicated simulations of the different systems.

The electricity tariff of the heat pump is lower than for household electricity. Actually, this argument was used in the installation phase to separate the two users. Further calculations could be done to analyze this prosumer model and to compare it with alternative models. This will potentially influence the other KPIs.

Conclusions

Energy and load profiles of buildings with energy production (and consumption) represent a new type of grid load that needs further recognition.

An optimization of the energy costs can be achieved by improving the operation of the building and of the PV system. However, changes in energy prices and tariff structures might influence the life-cycle energy costs and savings.

When planning the renovation measures, the following steps should be included:

- Tariff structures analysis and changes over time (decades)
- PV system (not only parameters orientations, shading, size, costs) optimization considering different tariff structures. This will be crucial when considering additional energy storage options (batteries with shorter life spans).
- Sensitivity analysis of PV system over a longer period (several years) and including weather data

Next steps include:

- Inclusion of energy to operate the heat pump
- Consider battery storage to improve overall performance
- Further analysis of solar radiation and electricity production

Acknowledgements

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Let the Sun Shine In, or Not: Automated Shades Improve Comfort and Energy Savings in Smart Homes

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Abstract

Daylighting and solar heat gain through windows can provide added interior comfort to home occupants if properly managed, but unwanted heat transfer through windows can account for a significant percentage of a home's peak cooling load in the summer and heating losses in winter. Automated interior insulated shades and exterior shades offer the potential to reduce and optimally control these heat gains and losses. As automated versions of these shading devices have become available, questions have arisen as to how much energy they can save, what operating schedules are most ideal for optimizing savings, and consumer acceptance of these control strategies. To answer these questions, our organization has conducted studies at our Lab Homes site: two fully monitored, identical, side-by-side homes where interior and exterior temperatures as well as heating and cooling energy use can be continuously measured and recorded. These Lab Home studies have been supplemented by field studies conducted at occupied field sites to measure shade usage, document installation practices, and survey customer perspectives. The testing was designed to assess the heating, ventilation, and air conditioning (HVAC) savings for both heating and cooling seasons resulting from the thermal insulating properties as well as the automated and dynamic control strategies of these various shading devices. Across the experimental studies at PNNL's Lab Homes, the examined shading technologies and control strategies resulted in daily HVAC energy savings ranging from approximately 1 to 7 kWh. These experiments demonstrate that reliably controlled, thermally efficient window coverings can enhance occupant comfort while dramatically reducing the heating and cooling energy use in a home.

Introduction

Residential buildings in the United States currently require 8 quadrillion Btu/yr of energy for heating and cooling. That accounts for more than 40% of primary residential energy use [1]. Windows are a major source of a home's heating losses and gains, with impacts on peak heating and cooling loads. Over the past 20 years, residential window attachment retrofit technologies have been developed that significantly increase the options available to home builders, homeowners, and utilities when considering upgrades to overall window performance. For this paper, the term window attachments is defined as interior and exterior products that are installed over windows, doors, or skylights in both residential and commercial buildings. In the U.S. market, interior products are often referred to as window treatments or window fashions; they can include blinds, shades, drapes, shutters, and films. Exterior products include roller shades, roller shutters, and awnings. Attachments also include both interior and exterior storm windows.

In 2013, the U.S. Department of Energy (USDOE) sponsored a comprehensive energy modeling study led by Lawrence Berkeley National Laboratory (LBNL) that focused on a range of window attachments, including products such as shades, blinds, storm window panels, and surface-applied films simulated in four types of "typical" houses located in 12 characteristic climate zones. The simulations captured the optical and thermal complexities of these products [2] and also considered typical operation and usage patterns based on a separate study that focused on user behavior with respect to operable window attachments [3]. These studies concluded that with appropriate operation, high-efficiency window coverings such as insulated cellular shades (see Figure 1) can significantly help minimize heat losses during the winter and heat gains during the summer and can decrease the overall annual home energy use. Results also demonstrated that exterior shades (see Figure 1) could effectively reduce solar heat gains outside of the envelope, which significantly improves occupant comfort in both conditioned and unconditioned homes during the cooling season.

Figure 1. High-performance window attachments include insulated cellular shades (left) and, exterior shades (right). *Sources:* AERC.

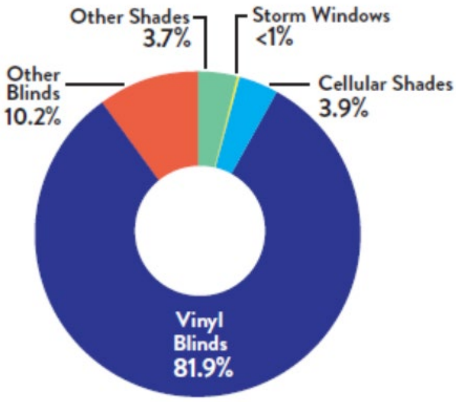
This paper compares recent field research on highly insulated cellular shades and exterior shades [8] with experimental evaluations conducted at the PNNL Lab Homes located at the U.S. DOE's Pacific Northwest National Laboratory (PNNL) in eastern Washington State [8]. In the lab Home studies, performance data from insulated cellular shades and exterior shades installed in the experimental home are compared to data from a baseline control home with windows covered with vinyl venetian-style horizontal and vertical slatted blinds, which are the most prevalent coverings in the U.S. residential market. In addition, PNNL examined the exterior shades in three occupied field sites located in Richland, Washington, to assess their ease of installation and thermal performance and to survey homeowners regarding their impressions of the exterior shades in terms of comfort, aesthetics, and use. The savings from various dynamic control schemes, including occupancy control schemes, are also analyzed to assess the contribution of dynamic shades to a "smart" connected home design.

Review of Technology

Window shades and other window attachment technologies can improve the thermal and transmission properties of the window via coatings or coverings that, depending on the climate, decrease solar heat gain (by decreasing transmission of light through the window), IR light transmission, and the amount of thermal conduction or convection between indoor spaces and the outdoors. Window attachment products, particularly interior attachments, have traditionally been thought of as decorative features; however, these products offer a variety of benefits to homeowners, including energy savings.

In 2013, D&R International conducted a residential window coverings study [3] which estimated that 82% of residential windows in the U.S. have some sort of window covering. Based on a review of U.S. shipment data, the most predominant window attachment by far is the relatively low-performing vinyl, venetian-style blind (see Figure 2).

Figure 2. Estimated 2015 market share for interior window coverings [4]



Source: AERC 2018.

Residential blinds and shades have traditionally been made to be easily operated and adjusted manually to meet the home occupants' personal requirements and preferences. However, technological advancements have made it possible to include motorized and automated operation, providing added convenience, comfort, and security to the homeowner. The global automated blinds and shades market is expanding with North America and Europe currently leading in sales. Overall, the automated blinds and shades market grew at around 3% (annualized growth) over the last 5 years [5].

Insulated Cellular Shades

Within the interior window coverings category, honeycomb cellular shades (see Figure 1) typically have the highest R-values because of their layered or concentric designs. Introduced in the 1980s, cellular shades are designed to trap air inside pockets which act as insulators. This design can increase the R-value of the window covering and reduce the conduction of heat through the window that it covers. Insulating shades can also impact solar heat gains if managed properly; the insulating air pockets can also be lined with a layer of metallized Mylar, which minimizes conductive and radiant heat transfer, similar to the effect that a low-emissivity coating has on windows.

Exterior Shades

Exterior shades refer to shade technologies that are designed to be installed on the outside of buildings and that can effectively reduce solar heat gain through the window, which makes this technology primarily a cooling season application. Exterior shades can be applied as fixed or operable attachments. Operable residential-style exterior shade products are commonly installed on outside patios or decks and typically include a mechanical crank, rod, or motor to allow operation from indoors. The most popular products in recent years are those that are raised and lowered via a remote control that operates a motor integrated with the shade hardware.

The general components of the exterior shades evaluated in this study included the cassette, which houses the motor and raised shade; the shade fabric, available in varying colors and levels of openness (that is, the amount of open space in the fabric pattern of the exterior shade); and the track or guide which contains the shade at the desired plane. Motorized exterior shades may include a variety of optional accessories such as an integrated solar panel for powering the motor and a wind sensor that raises the shade during periods of excessive wind speeds.

Controls and Automated Window Attachment Systems

Along with the added insulating properties of the shades, some of these attachments have built-in automation features to assist in optimizing the management of solar gains throughout the year. Automated shade systems can operate using sensors and controls, real-time weather data, schedules, programs, and/or algorithms, which allow the window coverings to open and close in response to predefined schedules or signals. Scheduling can be optimized based on the solar calendar and geographical location to reduce the HVAC load while ensuring that adequate light and thermal comfort are achieved within the conditioned space. For example, during the heating season, the schedule can be operated to maximize the duration of visible light and solar heat gain to the space during the daylight hours. Of course, the automated controls also allow the shades to be controlled based on other homeowner preferences, such as privacy and security preferences.

Window attachments can be motorized using power from batteries, electrical outlets (i.e., plug-in), or hard wiring. A battery-operated window attachment has the advantage of not needing electrical connection and does not require installation from an electrician but is best suited for smaller or lighter window attachments. A plug-in window attachment control also does not require an electrician, but outlets and cords can be unsightly if not designed into the construction of the building. An outlet-powered window attachment controller typically uses a direct current motor and is best suited to power low- to medium-weight window attachments. Hard-wired systems are usually installed during construction and typically use stronger motors that are well-suited for heavier window attachments or systems of multiple window attachments. There are several companies that offer residential-style motorized window attachments and automated systems, including North American market leaders Hunter Douglas PowerView®, Lutron Caséta®, Rollease Acmeda AUTOMATE™, Somfy Systems, and Spring Fashion's Graber Virtual Cord®.

PNNL Lab Homes Experiments

The window attachment studies featured in this paper use the PNNL Lab Homes testing platform (Figure 3) to examine the performance of both cellular shades and exterior shades. The Lab Homes consist of two side-by-side identical manufactured homes designed to represent existing U.S single-family residences, with one home serving as the Experimental Lab Home while the other serves as the Baseline Lab Home. Each home contains a central air-conditioner and ductwork. The 13-SEER (seasonal energy efficiency ratio) air-conditioner is controlled by an ecobee4 thermostat located in the home's hallway. Envelope air leakage and duct leakage are regularly evaluated at the Lab Homes to ensure comparable levels exist in each home. The Lab Homes contain nine double-pane clear-glass windows including three south-facing windows and two west-facing windows. One of the south-facing windows and one of the west-facing windows are sliding glass doors. The performance rating of the windows installed in the Lab Homes is provided in Table 1.

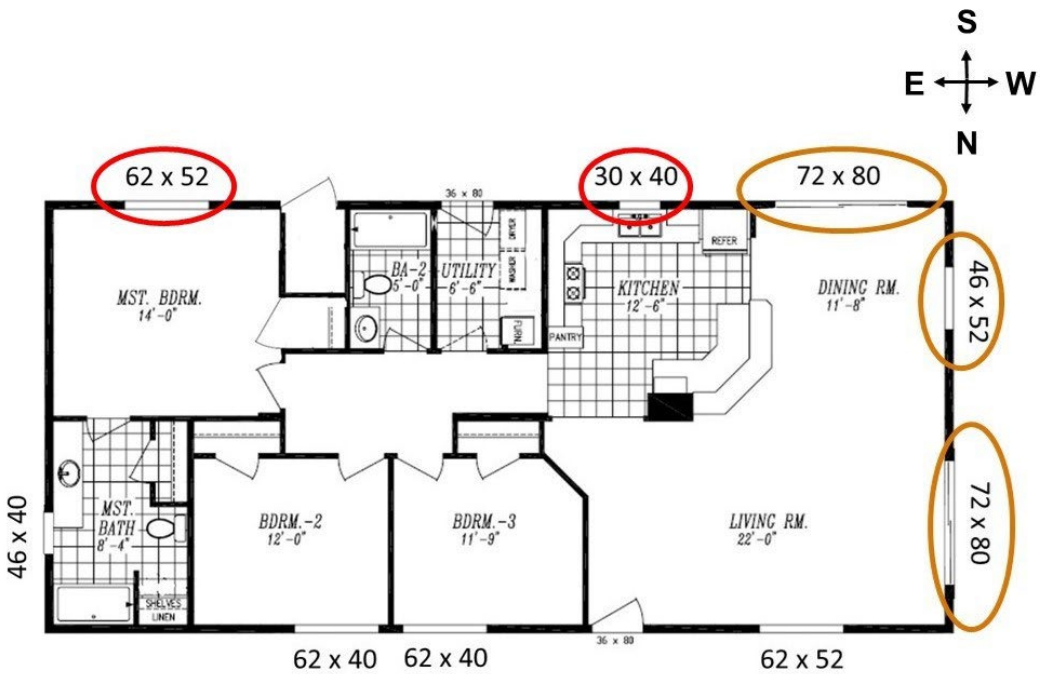
Figure 3. Side-by-Side PNNL Lab Homes

Table 1. Performance Characteristics of the Lab Home Windows

Value	Windows in Lab Homes	
	Windows	Patio Doors
U-factor (Btu/hr-ft^2-°F)	0.68	0.66
Solar heat gain coefficient	0.7	0.66
Visible transmittance	0.73	0.71

Figure 4 provides a layout of the Lab Homes and identifies the location of the key windows for both the exterior and interior shade studies. The three windows where shades were applied in the exterior shade study included a south-facing sliding door, a west-facing widow, and a west-facing sliding door (all circled in gold in Figure 4). Due to their size and orientation, these three windows are significant contributors to the overall fenestration cooling load at the homes. For the interior cellular shade study, all windows included a window attachment, which is typical for interior shades; however, the benefits of optimal operation and automation were maximized when they included these same larger west- and south-facing windows.

Figure 4. Lab Homes Floorplan and Significant Windows for Shade Studies



Insulated Cellular Shades Thermal Performance

PNNL conducted a series of experiments during both heating and cooling seasons from 2016 through 2018 to examine the thermal performance of the cellular shades under three operating scenarios in comparison to baseline conditions, including several experiments where the windows in the Baseline Home were covered with vinyl slatted blinds [6,7]. The three operating scenarios are as follows:

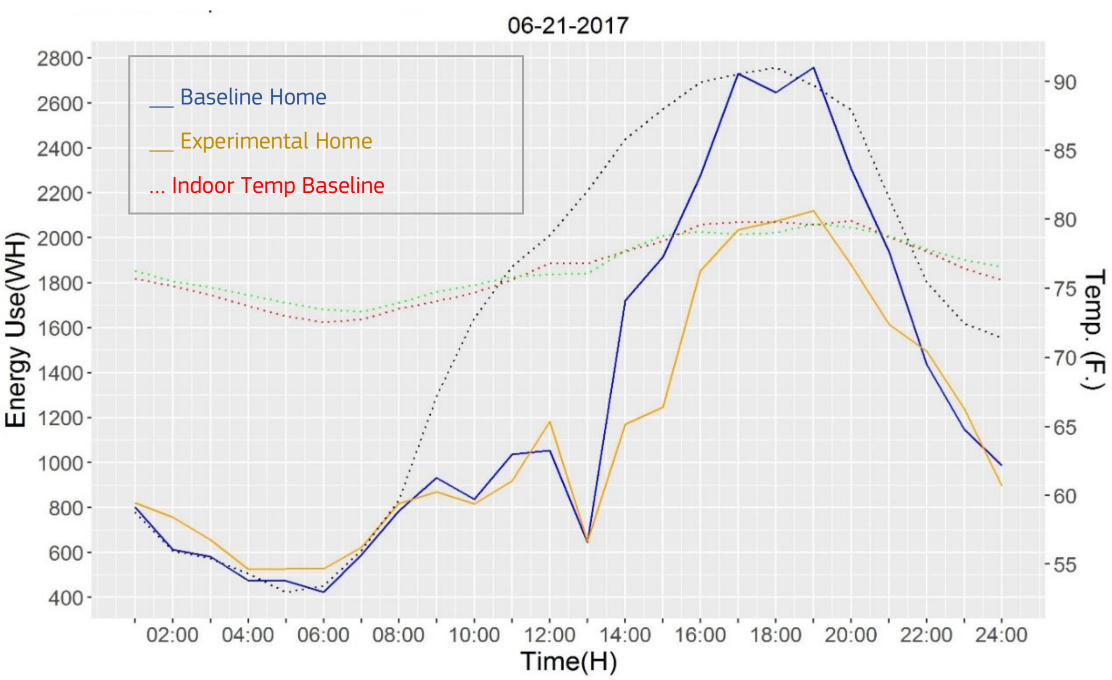
- "Static" Operation: During this experiment, the slatted binds in the Baseline Home and the insulated shades in the Experimental Home remained closed throughout the day and night.
- "Typical" Operation: During this experiment, the window coverings in both homes were positioned in a manner that reflected "typical use" based on a 2013 behavioral study (Bickel et al.), where the shades and blinds in the bedrooms were kept in the closed position both day and night, and the shades and blinds in the common areas and view areas (e.g., living room, dining room, and kitchen) were kept open both day and night. To reflect the finding that people rarely move the window coverings, the positions under the "typical use" scenario were not changed throughout the day or night.
- "Optimal" Thermal Operation: The "optimal" operation schedule was designed to maximize energy savings. While variations on this operation were evaluated, the optimal energy-saving operation during the heating season consisted of raised (opened) blinds or shades during the day to allow in beneficial heat gains and lowered (closed) blinds or shades during the evening to reduce the amount of heat escaping through the windows. The optimal operation during the cooling season involved keeping the shades or blinds down (closed) throughout the day. Thus, for the cooling season, the optimal operation is the same as the static operation.

Tests were designed to assess the heating and cooling season savings resulting from the thermal insulating properties as well as the automated and dynamic control strategies of the shading devices. As shown in Table 2, the insulated cellular shades thermally outperformed the vinyl blinds under all operating scenarios. These savings, however, were lowest when the shades remained in "typical use" settings throughout the experimental period, which implies savings potential for optimized automated shade controls.

Table 2. HVAC Savings for Cellular Shades vs. No Shades or Vinyl Blinds in PNNL Lab Homes

Experimental Home	Baseline Home	Season	HVAC savings (Average daily %)	Average W-hr daily savings
Static Operation: Cellular shades always pulled down on all windows (= optimal cooling season operation)	No shades covering windows	Cooling	24.8 (±8.6)	3,359
		Heating	2.4 (±3.2)	1,970
Static Operation: Cellular shades always pulled down on all windows (= optimal cooling season operation)	Vinyl blinds, always pulled down	Cooling	13.3 (±1.3)	2,650
		Heating	9.3 (±1.9)	7,011
Typical Operation: Cellular shades; bedrooms closed, living/dining open.	Vinyl blinds, typical use operation	Cooling	5.8 (±0.5)	1,487
		Heating	2.0 (±1.3)	1,505
Optimal Thermal Operation: Cellular shades operated optimally in all rooms	Vinyl blinds, optimally operated	Cooling	15.3 (±2.9)	3,211
		Heating	16.6 (±5.3)	5,766
Optimal Thermal Operation: Cellular shades operated optimally in all rooms.	Vinyl blinds, typical use settings	Heating	8.7 (±1.2)	5,445

Figure 5. Cellular Shades Cooling System Savings



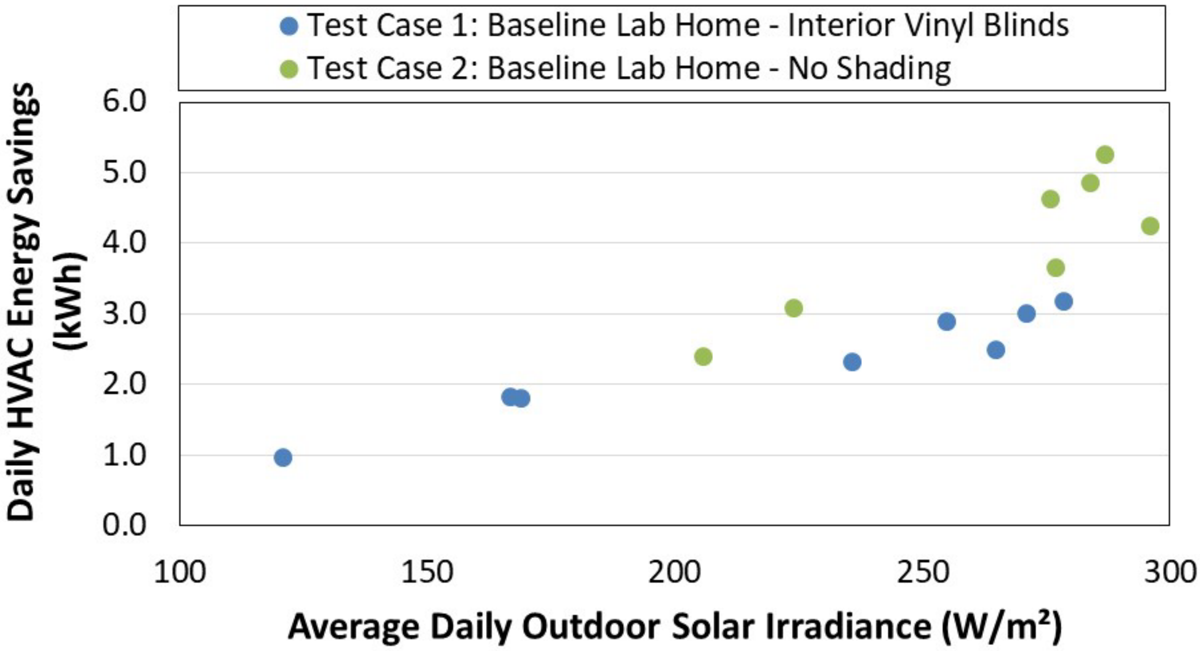
Exterior Shades Thermal Performance

To assess the performance of residential exterior shades, PNNL performed a series of field studies for exterior fabric shades during the cooling seasons of 2019 and 2020 [8] where the performance of the exterior shades was evaluated at the PNNL Lab Homes and three occupied field sites in Richland, Washington. At the Lab Homes, the energy performance of the exterior shades was evaluated in a controlled side-by-side environment. At the occupied field sites, exterior shades were characterized by measuring shade usage, documenting installation practices, and surveying customer perspectives.

Figure 6. PNNL Lab Homes shown with exterior shades rolled up (closed) and rolled down (open)

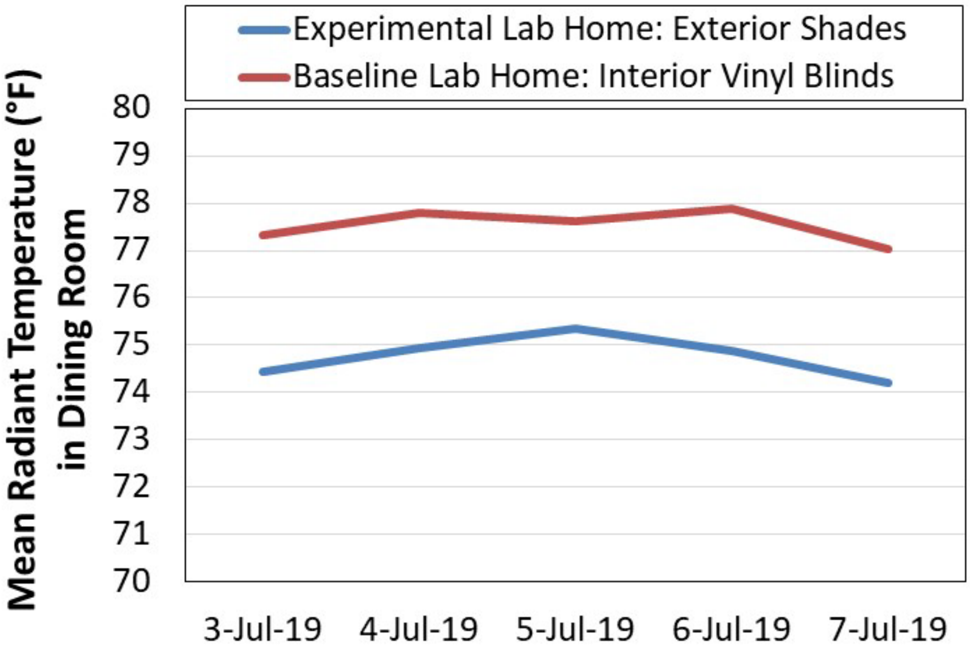
At the Lab Homes, the application of exterior shades on three larger west- and south-facing windows yielded cooling HVAC savings of approximately 20% (daily savings from 2.4 to 5.2 kWh) when compared to the Baseline Home, where the same three windows were left uncovered. When compared to interior vinyl blinds, exterior shades demonstrated daily HVAC energy savings from 1.0 to 3.2 kWh, which equates to approximately 10% savings for space cooling during the experimental time period. Figure 7 shows the range of kWh savings for both experiments as a function of outdoor conditions.

Figure 7. Exterior Shades Cooling HVAC Savings as a Function of Solar Irradiance



The application of exterior shades also facilitated a more comfortable indoor environment, where indoor temperatures in the rooms with exterior shades covering the windows were around 3°F (1.67°C) cooler than the same rooms in the Baseline Home where the windows were covered with vinyl blinds (see Figure 4). Heat transfer through the dining room sliding door was examined by taking a center-of-glass, interior surface temperature measurement, which was up to 4°F (2.22°C) warmer in the Baseline Lab Home, which was covered with vinyl slat blinds.

Figure 8. Indoor Temperatures Near Covered Windows



In a no-cooling (i.e., home without air-conditioning) test case, the home with exterior shades was 9°F (5°C) cooler than the home with vinyl blinds on a sunny day where outdoor mid-day temperatures were around 75°F (23.89°C), suggesting that exterior shades could be an effective measure to control solar gains and improve occupant comfort for homes without mechanical cooling in mild climates [8].

Shade Automation Benefits and Opportunities

Operable window attachments give users the ability to use them as they see fit. This user control may or may not lead to energy savings, which can sometimes be seen as a drawback from an energy efficiency standpoint. However, the ability to operate window attachments can also provide a dynamic element to a standard window that extends beyond the insulating properties by operating them in a manner to allow solar gains when beneficial during the winter and reduce solar gains in the summer.

Interior Cellular Shade Operation and Automation

Summer Shade Operation

Although the optimal summer shading strategy from an energy-efficiency perspective may be to keep the shades closed all the time, this type of strategy could run counter to a building occupant's desire to see the outdoors and allow in full amounts of natural light. However, building occupants typically choose to keep the shades closed for reasons of security or for added privacy. Thus, if the home is unoccupied during a summer day, the closed shade setting would be ideal from both an energy-efficiency and security standpoint. With this in mind, we examined the effects of two control strategies using an energy-efficient schedule[256] and an occupancy control scheme that recognizes when the home occupant is away at work or school during the day. In both cases, these operation schemes only operated the shades in the common area of the Experimental Home while the remaining windows were set in the "typical use" position. The Experimental Home was then compared to the Baseline Home where all windows had vinyl blinds that were operated with "typical use" settings. Both operation schemes were implemented using the same automation system. Table 3 shows the

[256] The energy-efficient schedule is specifically designed to optimize HVAC operation and solar heat gain while allowing some daylighting to accommodate consumer needs for natural daylight.

results for these two experiments, demonstrating that these straightforward automation strategies yield significant cooling savings during the experimental period, with outdoor temperature highs ranging from 83°F to 95°F (28°C to 35°C).

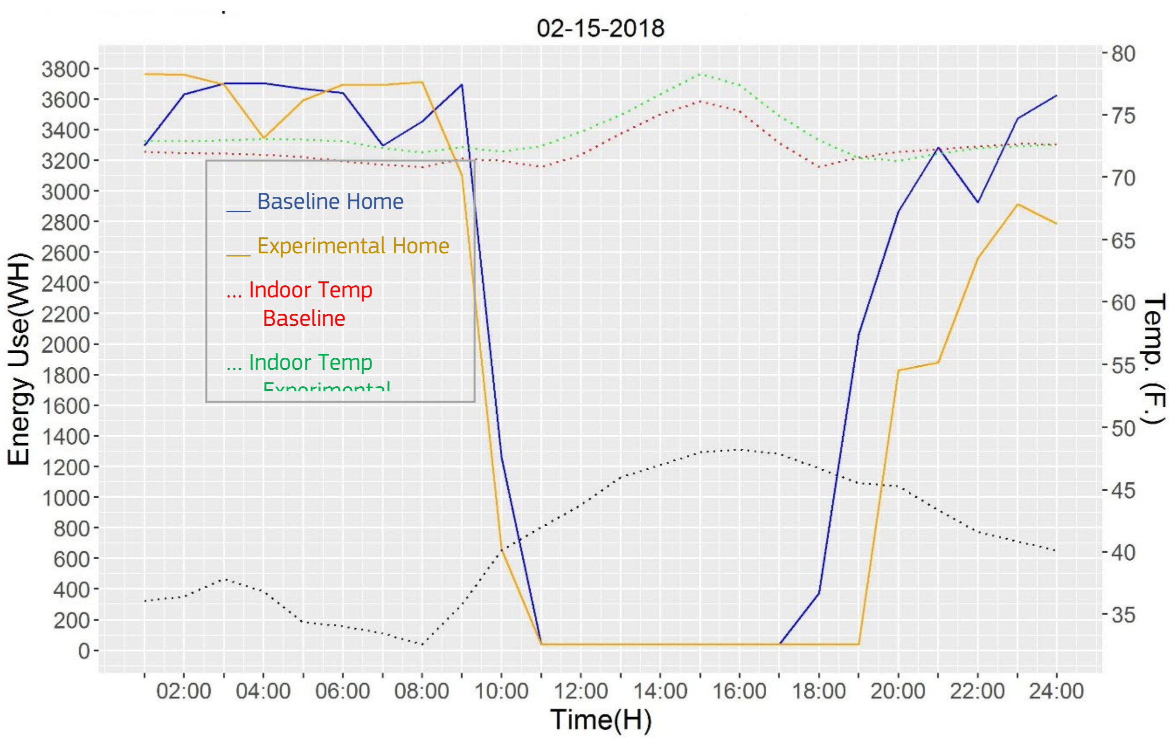
Table 3. Shade Automation Savings

Experimental home	Baseline home	HVAC savings % (+/- 95% confidence)	Average outdoor temp (°F)	Average W-hr/day savings
Partial optimal control: HD Green schedule for common area rooms, typical use in all other rooms	Vinyl blinds, typical use operation	15.1, (±2.0)	77.4	3,287
Occupancy Control: Cellular shades closed in the common area from 9AM to 5PM and typical use operation during all other hours	Vinyl blinds, typical use operation	15.2, (±2.2)	76.4	3,814

Winter Shade Operation

Similar whole-home testing of cellular shades was conducted during the heating season and compared to typical vinyl blinds under different operating scenarios. One of the key findings was that, during the winter months, the beneficial heat gains through the south- and west-facing windows significantly contribute to reducing the home's heating load during the daylight hours, particularly on cold sunny days in homes with clear glass windows. Most of these beneficial heat gains are not realized when the shades are pulled down during daylight hours. For the heating season testing, a variety of different operational settings that opened the shades at least to some degree during the day and closed them at night were able to produce consistent HVAC savings (average of 6–9%) in the home with cellular shades, whether it was just partial operation of the large west- and south-facing common area windows, or full operation of all windows. When all the windows with cellular shades were raised (open) during the day and closed at night in the Experimental Home (see Figure 8), the average HVAC savings were 9% compared to the home with typical vinyl blinds operated in the same "typical use" manner as the cooling season.

Figure 9. Whole-house HVAC Savings from the Application of Optimally Operated Cellular Shades



Exterior Shade Operation and Automation

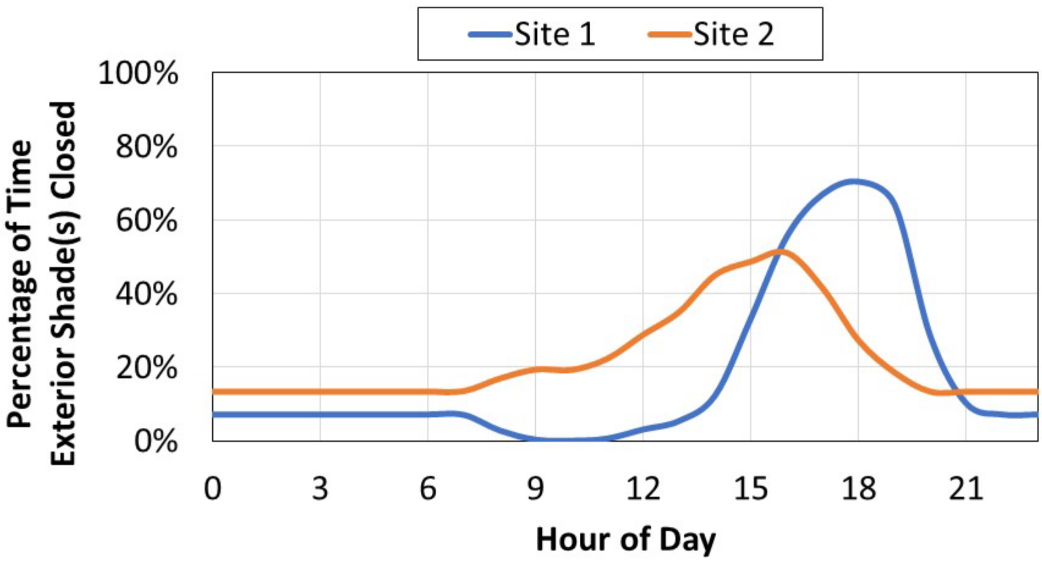
During the 2020 summer cooling season, PNNL evaluated exterior shades at three occupied home field sites in Richland, Washington to help characterize performance, installation practices, and usage in a real-life application. Sites 1 and 2 were installed with side tracks while Site 3 was installed with wire guides on the side and included a wind sensor that would raise the shade during periods of excessive wind speeds. The position of the shade was tracked by two contact closures mounted along the track of the exterior shade at Sites 1 and 2 while shade position was manually logged by the homeowner at Site 3. All of the exterior shades were motorized and could be controlled remotely. Figure 9 shows the views from inside the home through fully shaded windows at the three occupied field sites.

Because exterior shades are primarily a summer cooling season application, the optimal operation from an energy-efficiency standpoint is to pull the shades down during the afternoon and early evening to reduce heat gains through the windows. As shown in Figure 9, one key benefit of exterior shades that was noted by homeowners is that the view to the outdoors is maintained during daylight hours even when the shades are pulled down. This benefit was noted as helping to facilitate optimal operation where homeowners kept the shades fully deployed during the heat of the day to reduce heat gain and glare through these west- and south-facing windows while maintaining the views to the outdoors in their dining rooms.

Figure 10. View Outside during Sunlight with Exterior Shade Closed at Occupied Field Sites

Figure 10 shows that the homeowners operated the shades in a manner that optimized energy efficiency by keeping the shades pulled down during the afternoon hours. The homeowners of all three field sites reported satisfaction with their application of the exterior shades. The homeowners were particularly satisfied with the exterior shade's ability to reduce glare while preserving a view to the outdoors. The homeowners also found the exterior shades to be reliable and easy to use while providing improved comfort in the indoor space. Improved occupant comfort, in terms of reducing the indoor temperature, was confirmed with field measurements at all three occupied field sites.

Figure 11. Exterior Shade Use by Hour of the Day



Energy Ratings and Emerging Opportunities

Standards and ratings can help inform consumers and drive the market for energy-efficient products. To address the lack of energy-related ratings or standards for window attachments, USDOE helped launch the Attachment Energy Rating Council (AERC) in 2014. AERC is an independent, non-profit, rating council that has developed a comprehensive energy-rating, labeling, and certification program for window attachments, which provides accurate and credible information about the energy performance of rated products to the public. AERC has energy ratings available for cellular shades, with plans to rate exterior shades in 2022.

The current AERC energy ratings for operable shades presume a manual operation of the shades in sub-optimal manner. The emergence of motorized operation and automated controls presents opportunities for expanding the market and providing additional energy savings from window attachments. To recognize these features, AERC has developed schedule-based automation control algorithms and energy performance ratings for the standards' heating and cooling climates. The automation schedules are based on seasonal deployment patterns that reduce heating and cooling energy use compared to manual operation, while minimizing the number of shade movements. The Automation Energy Performance ratings provide a standardized comparison for energy savings potential between automated attachments while allowing innovation from individual manufacturers to utilize their own control parameters in commercial products.

Conclusion

While approximately 80% of the 118 million U.S. residential housing units have some form of window covering, over 80% of these installed window attachments are made up of relatively low-efficiency (e.g., vinyl blind) coverings [1,3,4]. Across the experimental studies at PNNL's Lab Homes, the examined shading technologies and control strategies resulted in daily HVAC energy savings ranging from approximately 1 to 7 kWh. There would therefore appear to be a large market opportunity to shift consumers from less efficient window attachment products toward higher efficiency products such as high efficiency cellular or exterior shades. These savings potentially quadruple when "smart" energy-efficient operation of the shades occurs year-round, which could be facilitated with automated shading systems [1,7,9]. This would suggest that there is a need in this sector to help inform and educate consumers about "smart" energy-efficient operation and features of window coverings in order to help consumers fully realize energy savings from high-efficiency window attachments.

Although window attachments that are manually operated can present challenges to ensure persistent savings, the emergence of automated controls in this market presents opportunities for expanding the market and providing energy savings from window attachments. New and emerging integrating platforms can also optimize shade control based on weather conditions and occupancy status. Dynamically controlled high-efficiency cellular shades can provide significant year-round savings and should be considered an important component of any "smart" home design. The addition of energy ratings and labels for window attachment and field-validation research can help consumers, designers, builders, and home performance contractors make informed decisions about window improvement retrofits. There is also an opportunity to improve efficiency by encouraging "smart" operations of these devices through education and automation. Together these opportunities could help to save some of the vast amounts of energy we lose through windows each year.

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7 BEHAVIOUR

Empowered operators to provide direct advice on consumption habits to mitigate energy poverty with special relevance to summer energy poverty (COOLTORISE project)

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Abstract

The paper presents a general overview of the energy poverty phenomenon, analysing also the most recent impacts due to climate change and the COVID-19 pandemic and how it is intrinsically linked to the just and inclusive transition.

It describes the research process carried out in the last years leading to the definition of the Household Energy Advisor (HEA), its characteristics, and its training and more in general the ASSIST model, based on the HEAs outcomes of the Horizon2020 ASSIST [1]. Moreover, the further application of the role of HEA, in the so-called summer energy poverty, will be described through the description of the Horizon2020 COOLtoRISE project. Both the projects, ASSIST and COOLtoRISE, are inspired from the SMART-UP project.

Building on the experience of these three European projects this paper concludes that human direct contact and adequate socio-technical skills are crucial in combating energy poverty by complementing hard measures with softer ones. Moreover, the focus area are Italy and Spain (where all the three projects have been carried out) where the need for a reference operator, capable of guiding consumers in the changing energy market, advising them, assisting them, and increasing their knowledge is now clearly recognised.

1. Introduction

Literature and actions on the ground have highlighted the risk that energy transition may be neither just not fair, but it can increase the gap between rich and poor people, with the dangerous veneer of favouring specific classes of the population [1-2]. In fact, the effects of such risk would be mostly borne by the most vulnerable citizens with the consequence of widening the social gap.

Therefore, the energy transition, rather than ensuring an overall societal transition to a more sustainable and inclusive economy, would actually increase the percentage of European citizens living in energy poverty. This process would occur by pushing all those citizens that today are at risk of falling into poverty, into actual energy poverty and further worsening the conditions of those who are already affected by energy poverty.

In parallel to the European energy policy frame, two other factors need to be taken into account when dealing with energy poverty: 1) the negative consequences of the COVID-19 sanitary-economic crisis [3] and 2) climate change leading to an increase in the summer average temperatures and the occurrence of summer heatwaves.

Whilst the former factor has had negative effects on all the population, exasperating the situation of those in energy poverty / vulnerability, the latter has led to a new facets of the energy poverty phenomenon with direct consequences on citizens in energy poverty / vulnerability during the summer - the so-called summer energy poverty where people are not able to keep cool houses during hot periods.

These multiple and inter-connected considerations lead to a simple understanding: energy poverty (and summer energy poverty) is an issue which needs to be faced with appropriate and effective actions at different levels of governance and on the ground actions, with the aim to enforce assistance support mechanisms and put in place long lasting empowerment strategies to directly support people in need.

It is in this context that the role of the Household Energy Advisor, enables a holistic approach to the problem of energy poverty (and summer energy poverty) by representing an important and unique reference point for citizens for all energy poverty related issues. The concept of Household Energy Advisor was designed within the framework of the Horizon 2020 ASSIST project. It is defined as an operator on-the-ground coming from different working contexts specifically trained on social and human aspects of energy poverty/vulnerability.

This paper has the goal to present the studies carried on the concept of empowered operators initially on energy poverty and more recently on summer energy poverty in various European Horizon2020 projects - SMART-UP [4], ASSIST [5] and COOLtoRISE [6], each building on the experience gained from the previous research projects and parallel initiatives.

By tracing the 3 key stages of the research carried out in the field of energy poverty, this paper focuses on the new innovative role played by the HEA, acting as an intermediary between vulnerable citizens and technical experts, being able to provide the needed support and increase awareness/ knowledge of citizens:

1. The Horizon2020 SMART-UP project, centred on the use of smart metres to encourage consumers to be aware of their energy consumption habits and improve them, accordingly, addressed the well-known difficulties in identifying and communicating with vulnerable people. For this reason, the project has had the merit of considering first-time people from the social environment as operators with an active role to address the energy poverty issue. SMART-UP proved that social operators are indeed operators on the ground already in contact and with a trustworthy relationship with citizens in energy poverty, able to have an open dialogue with them and therefore in an ideal position to provide the needed advice. However SMART-UP also highlighted the need to empower social operators on energy related issues to provide them with the knowledge and capacity to actually provide citizens in energy poverty with the needed advice and therefore actually have a positive impact.

2. The second stage consists of the Horizon2020 ASSIST project, which ended in June 2020. Building on the conclusions of SMART-UP, ASSIST, successfully tested in 6 countries (Italy, Belgium, Finland, Poland, Spain, UK), developed a three-step approach to ensure a concrete and on-the-ground assistance model to energy poor consumers based on three steps or phases: 1) training; 2) networking and 3) action of HEA, i.e., operators working in different sectors (i.e., energy, social, wellbeing) and in different context (i.e., public, private, associations) [7]. ASSIST enlarged the concept of SMART-UP and concluded that all on the ground operators, not only social operators, if properly trained / empowered, may provide advice to energy poor citizens. The promising results of ASSIST and the growing problem of energy poverty have led to a European initiative to further upscale the ASIST model in 5 European countries (Bulgaria, Italy, Poland, Romania, Spain) - the SUITE project. While efforts to scale the ASSIST model continue (see chapter 3), research is also working to include new emerging issues in the field of energy poverty.

3. Building on the ASSIST model and enlarging the scope of energy poverty to include the summer energy poverty, the research has started its third stage within the COOLtoRISE project, running since September 2021.

   The project, as we will see in chapter 7, includes four countries: Bulgaria, Greece, Italy and Spain and it aims to reduce summer energy poverty incidence among European households, improving their indoor thermal habitability conditions and reducing their energy needs during the hot season, which will in turn decrease their exposure to heat and heat-related health risks. The project, to achieve these objectives, foresees the training of a new role, the summer energy poverty agent (SEPA), an operator that will implement actions, targeted at the most vulnerable householders, to reduce summer energy poverty.

2. Energy poverty in the context of the Just Transition

Nowadays it is estimated that more than 50 million households in Europe live in a situation of energy poverty [8], and this number may vary considerably in the next future due to many different factors, such as increase in energy prices and market instability related to the Russo-Ukrainian war and the recent sanitary crisis related to COVID-19. Furthermore, the Covid pandemic has forced many people at home, increasing the energy consumption and often significantly reducing incomes of households with more precarious jobs.

The data collected by the European Energy Poverty Observatory shows how in 2018, 6.6% of the population had arrears on utility bills, and 7.3% were not able to maintain a comfortable temperature in their homes [8].

Additionally, in 2015, 16% of European families had a share of energy expenditure in income more than twice the national median share [8].

While in the common imagination energy poverty is still represented by an idea of cold, lack of heating and winter discomfort, in recent decades a worrying trend has been developing, especially in the Southern Europe countries, and becoming a distinctly recognised phenomenon, that of summer energy poverty [9].

It is evident that the climate is changing, and that these changes will have a negative impact on well-being. For example, the 2003 European heat wave brought an undeniable increase in mortality, 22.9% of excess deaths were calculated in Spain and 4.9% in England and Wales [10].

Rising temperatures will affect the most vulnerable groups in society [11], who will continue to be more exposed to heat-related mortality, such as heat stress or disease. Among the main reasons are low-income, high-energy bills and low energy efficiency housing. This situation becomes even more complex if we consider how temperature has a rising trend: the last five years have been defined as the hottest ever, and 2019 has been identified as the year in which temperatures have reached levels above the average [12].

The other key factor aggravating the condition of energy-poor people has been the COVID-19 pandemic which has exacerbated existing vulnerabilities and inequalities, including household energy consumption. The lockdowns and restrictions have drastically increased the amount of time people spend at home, and consequently the energy needs of households. During lockdowns, the houses became a totalizing space, hosting a range of activities that previously took place outside. This led to higher use of heating (to stay warm all day), hot water (to wash hands often), cooking (to prepare food at home instead of eating out), and lighting. New energy demand fronts have also emerged, such as electricity for distance working, distance learning and home recreation (such as extensive use of streaming platforms, etc.).

For many households, energy expenditures increased at the same time as the devastating effects of the pandemic on the labour market radically reduced incomes. In other words, many households faced higher energy costs on lower incomes, in particular people with low income have found difficulties due to the increase of the energy bills. Other vulnerabilities intersect at this point, i.e., households with low incomes often live in less energy-efficient homes and must use more energy to achieve the same level of services than households living in more-efficient homes.

Considering this, it is easily understandable how energy poverty becomes a key priority in all European countries, even if a common European definition does not exist yet [13]. However, both the scale of the problem and the severe physical and mental health impacts caused by energy poverty are widely recognised: severe health issues and social isolation [14]. The European goal of creating a green and just transition will never be achieved without a capillary and holistic answer to the problem of energy poverty, in both the declination of traditional energy poverty and summer energy poverty [15]. E*nergy Poverty has become more and more relevant in the political spheres, and this is recognisable in a series of different legal initiatives.*

At the global level, the UN's 2030 Agenda for Sustainable Development provides a reference framework for tackling energy poverty by strengthening coherence between the Sustainable Development Goals (SDGs). SDG 7 on 'Clean and Affordable Energy' is strategic for economic development, SDG 1 on poverty reduction, SDG 10 on reducing inequalities and SDG 3 on good health and well-being reinforce the links with poor thermal comfort and indoor air quality. The United Nations highlight how progress towards the reaching of all the SDGs and, more in general, of the Just Transition must consider the increased access to energy supply and services for vulnerable consumers as a necessary and urgent intermediary step.

The European Union is committed to tackling energy poverty as a priority in its long-term energy transition towards an environmentally sustainable and climate neutral economy. As part of the energy transition, the Green New Deal [16] sets tackling energy poverty as a priority to ensure the supply of clean, affordable, and secure energy to all EU citizens and households. Prior European policy instruments dealing with energy poverty are the Clean Energy for all Package (May 2019), which outlines the phenomenon of energy poverty and invites Member States to tackle it. In particular, the directive (EU) 2019/944 concerning common rules for the internal market in electricity,recognises energy technologies and consumer empowerment as effective means to advance energy efficiency at household level and help combat energy poverty. The new Energy Efficiency Directive (EU) 2018/2002 requires Member States to provide information on the results of measures to alleviate energy poverty under this Directive in their integrated national energy and climate reports in accordance with Regulation (EU) 2018/1999. The definition of energy poverty is referred to the Member States as set out in Regulation (EU) 2018/1999 on governance of the Union for energy and climate action. In their integrated national energy and climate plans, Member States should assess the number of households experiencing energy poverty, considering household energy services needed to ensure a basic standard of living in their national context, existing social and other relevant policies, as well as indicative guidance from the Commission on relevant indicators, including geographical dispersion, which are based on a common approach to energy poverty. Where a Member State identifies a large number of households suffering from energy poverty, it should include in its plan a national indicative energy poverty reduction target.

Lastly, combining the European context with the local level, it is important to notify that municipalities that sign the Covenant of Mayors (CoM) not only take action to mitigate climate change and adapt to its unavoidable effects, but also commit to providing access to secure, sustainable, and affordable energy for all. Covenant signatories can improve the quality of life of their citizens and create a fairer and more inclusive society by reducing energy poverty. Also, the new European initiative, Energy Poverty Advisory Hub (EPAH [17]) aims to support a local approach to tackle energy poverty by providing direct support to municipalities to implement local initiatives to address energy poverty.

The framework outlined at European level sets ambitious targets and guides member states towards holistic and comprehensive action on energy poverty. However, the practical implementation of these directives is often hazier and confusing in individual countries. This calls for a more in-depth analysis of the practical tools traditionally used by member states.

3. Overview of the traditional responses to energy poverty and need of innovative on the ground instruments

As shown in the previous session, energy poverty is a phenomenon with several facets, incorporated in a complex socio-economic context [18]. Consequently, the causes can be found in the convergence of concomitant factors: low income (and therefore absolute poverty, high and increasing electricity and gas prices, poor energy efficiency of homes (poorly insulated houses and inefficient heating/cooling systems) and, often, high energy consumption due to low energy efficiency of the house and appliances [19].

The ASSIST "Vulnerable Consumers and Energy Poverty Report" [20] underlines how the majority of the instruments implemented by Member States only face the economical aspect of energy poverty, and often consist in temporary palliatives which are dependent on political decision. The 'hard' intervention actions are always accompanied by other forms of support, focusing on direct assistance to consumers; instead, the 'softer' instruments are used to inform and advise consumers with the aim of making a significant impact on their consumption habits. These latter include energy advice and the use of smart metres monitoring consumption to support households in changing the way they use energy and reduce energy consumption with a consequent reduction of bills. The urgency to fully integrate the human factor within the policy making as a "complementary disciplinary resource" to better define and address the problems associated with energy poverty continues to gain acceptance and support in the literature [21].

The possibility to inform and nudge consumer's behaviour has been the subject of many studies in recent years, through research activities conducted at European Level, gaining growing consent. The first step here analysed is represented by the Horizon 2020 SMART-UP project [4], funded to address energy poverty using Smart Metres and, in general, contribute to generate knowledge on how to engage with householders effectively and instigate energy-related behavioural changes.

SMART-UP partners identified the key issue of reaching vulnerable consumers as a major barrier when developing and actuating "soft" instruments to tackle energy poverty. Overcoming consumers' reluctance, convincing them to participate in awareness programmes and to follow the experts' advice was the major challenge of the project. For this reason, the partners decided to rely on the network of stakeholders who had already come into contact in various ways with vulnerable people, especially social workers. Allowing citizens to interact with people they already knew and had the opportunity to gain their trust on previous occasions made it possible to identify, approach and support vulnerable people. These stakeholders provided face-to-face advice to consumers on how to use smart metres, understand their energy bills and become more energy conscious. Thanks to the collaboration with the stakeholders, SMART-UP engaged with more than 5000 consumers in five countries (UK, Italy, Malta, Spain, and France), and identified the main challenges to be faced when trying to identify and reach vulnerable consumers:

- Lack of trust, unwillingness to share personal information and unwillingness to admit to being vulnerable/in energy poverty.
- Language barriers, low levels of literacy or other issues which made it difficult to communicate effectively.
- Lack of interest in energy and/or understanding of how actions could lead to reduced consumption.
- Difficulties in identifying which consumers had smart metres (in countries where the smart metre roll-out wasn't complete).
- Data protection and informed consent procedures, while necessary, also meant that the consortium was in some cases unable to engage directly with the consumers and instead was reliant on public bodies who did not always see energy poverty as a priority area.

The insight achieved within SMART-UP and other initiatives confirmed that intermediary operators can play a key role in creating the bridge of trust and continuity necessary to enter people's houses, convince them to share their consumption patterns and receive advice to change their inefficient habits.

4. The ASSIST Model

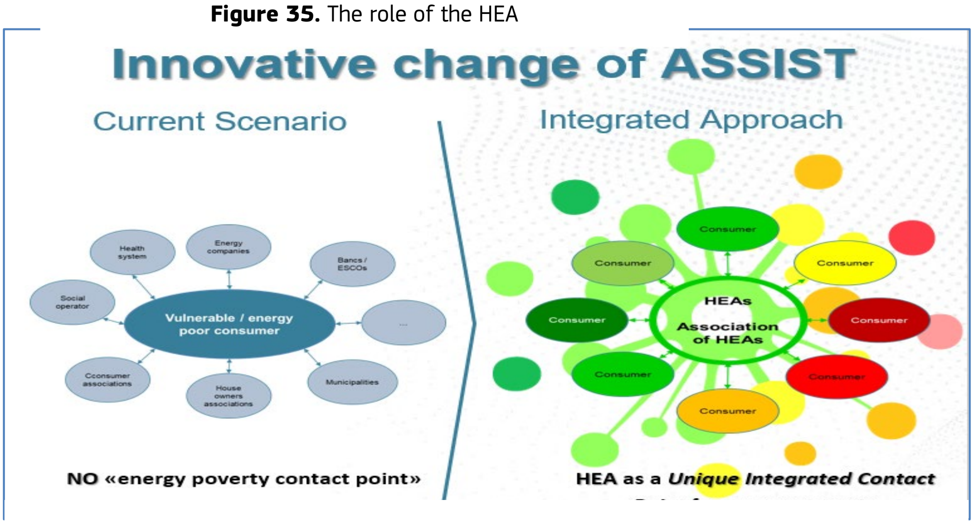
The results of the SMART-UP [22] project confirmed the need of an intermediary role but also underlined the consequent challenge of training these operators on the specific issues of energy poverty.

The underpinning concept of the ASSIST project was to analyse the knowledge and capacity needs of on the ground operators to be able to play a key role in mitigating energy poverty and at the same time to widen the field of work of the new operators in the social field.

In fact, the ASSIST Model, based on the multi-dimensionality of energy poverty, is an innovative holistic model to tackle energy poverty through the introduction of empowered operators coming from different working sectors and fields - the Home Energy Advisor (HEA).

The HEA (see Figure 1) is an innovative role having integrated skills to provide support to people in energy poverty. The HEA is defined as *"the figure being in direct contact with the target group (vulnerable consumers) to provide energy efficiency support to vulnerable consumers and more specifically to energy poor consumers. The HEA delivers information, support, and advice to them in an easy, comprehensive and practical manner to improve their energy consumption behaviours and also facilitate access for them to supporting financial measures/incentives*" [23]. The HEAs come from different working contexts, from social and charity entities to technical consultancies in the energy sector and public bodies, and after the training are able to fulfil three main roles: energy consumption behaviour analysis; energy behaviour support and check-up; advice and communication to citizens.

Figure 35. The role of the HEA



The importance of designing a centred approach is given by the fact that nowadays, people in distress are faced with multiple independent but interconnected problems, all related to energy poverty. This forces them to seek help from and interact with as many actors as they can. The ASSIST Model adopts a HEA-centric approach where HEAs have been trained on all aspects of energy poverty and are therefore able to be a single point of contact for the consumer by providing answers to the various energy poverty issues. The model also intends to bridge the alignment with the training and labour market regarding the adoption of a professional role able to talk with and assist people in energy poverty.

Moreover, the recent economic and health crisis due to COVID-19 has exacerbated the situation by shifting the poverty line to include households that were previously at risk of energy poverty, increasing consumer reluctance and the difficulty of 'letting' new people into the home. This has considerably increased the difficulty of identifying and reaching the vulnerable. As a result, the number of households in energy poverty has increased significantly and estimates show that this role will tend to grow further

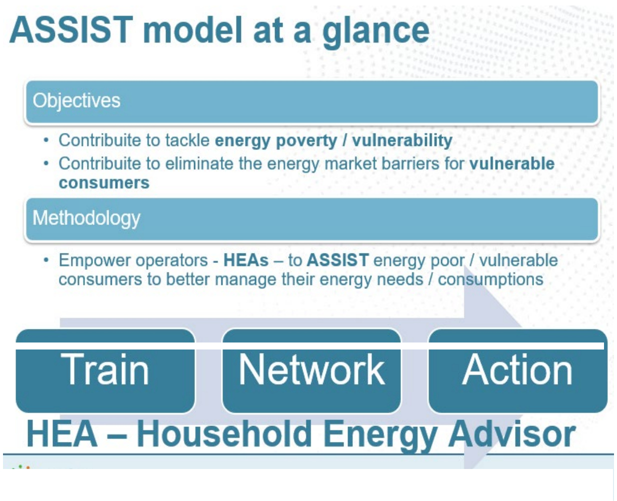
in the coming years. Therefore, an operator able to provide assistance to consumers in conditions of energy poverty/vulnerability is even more topical and demanding.

The model follows three steps or phases (see Figure 2): 1) training; 2) networking and 3) action with the goal to enable HEAs to inform, support and assist people in poverty or vulnerability.

The model fosters the creation of a direct bridge with people in difficulty to provide concrete help and support through the provision of direct and targeted services:

1. Access to the online training platform
2. Access to the training course according to the work context of origin (several training courses are available, customised according to the training gaps of the different targets of the model)
3. Access to the online workspace
4. Access to resources for the provision of information / support / ASSISTANCE services to people.

Figure 36. The 3-plases of the ASSIST model



Moreover, due to the multi-dimensional and multi-sectoral approach of the ASSIST model, reflecting the characteristics of the energy poverty itself, the model is proposed as a valid solution in many work contexts. The actors that can benefit from the adoption of the ASSIST model may come from various contexts, such as energy sector, social, institutional or private. The variety of actors in the network constitutes a further element of innovation and richness, also favouring the HEA-HEA circular dialogue and the exchange of experiences and competences. It is possible to conclude that the ASSIST model proves to be a win-win solution for all parties in tackling energy poverty.

5. ASSIST's results

ASSIST proposed several editions of the training course attended by operators coming from very wide and differentiated contexts: social workers and operators of the extended social system (including the specific consumer protection/assistance system); unemployed people; freelancers; consultants; students in work-related learning and university students (for the training of specialist social workers); researchers; operators/employees of companies in the energy and smart home sector; public employees. The results of ASSIST training showed the existence of a real interest among the different actors on the national/regional territory and the willingness to adopt the ASSIST model (based on the HEA role) to concretely contribute to the fight against energy poverty.

Moreover, in line with the approach of the model and with the evidence related to roles, occupations and profiles of the HEA, the distribution of the participants by degree of experience in the reference sector shows a rather balanced articulation: one third of the participants had no or minimal (less than one year) experience; the remaining two thirds distributed in the other experience bands, with a prevalence of the - even if minimal - central band (from 1 to 5 years). Following the training, the trained HEAs had access to the national HEA network and received support in defining and implementing concrete actions to support energy-poor consumers. Both activities (network and action) were analysed, and the evidence gathered demonstrates the effectiveness of HEA actions in the field.

Within the countries used as reference within this paper (Italy and Spain), three types of actions were delivered by the HEAs (see Table 1):

- **Soft/engagement activity** - informative actions addressed to a large number of target groups with a limited impact on energy consumption (estimated at 2% in the literature).
- **Action** - personalised support actions (1:1) with a high impact on consumption and quality of life of the consumers reached (impact calculated analytically with data collected before and after the action)
- **Synergy** - actions developed in synergy with other initiatives to combat energy poverty.

Table 1. ASSIST Actions carried out by HEAs in Italy and Spain

Type of Action (soft / action / synergies) in Italy	Type of Action (soft / action / synergies) in Spain
Soft/engagement activity #1 Advice at points of sale (Leroy Merlin)	*Soft/engagement activity #2* Energy cafès
Soft/engagement activity #2 Energy cafès	*Soft/engagement activity #3* Energy advice by coordinators of the Home Care Service
Soft/engagement activity #3 Support in accessing funding	*Soft/engagement activity #4* Energy advice by HEAs from Home Care Service for users that are not participating in the ASSIST actions
Soft/engagement activity #4 Information activities for disabled students	*Soft/engagement activity #5* Energy advice by HEAs from Tele Care Service for users that are not participating in the ASSIST actions
Soft/engagement activity #5 Energy café + information/training activities for social workers	*Soft/engagement activity #6* Sending advice through newsletters
Soft/engagement activity #6 Energy cafés at energy outlets	N/A
Soft/engagement activity #7 Energy cafés at social workers' premises	N/A
Soft/engagement activity #8 Training/information activities at trade union sites	N/A
Soft/engagement activity #9 Distribution of support material and information to consumers	N/A
Soft/engagement activity #10 Online help desk on energy bills and consumption habits	N/A

Soft/engagement activity #11 Consumer events	N/A
Action #1 Home visits and personalised support by social workers	*Action #1* Home visits in the urban area by home care professionals
Action #2 Help desks for consumers in poverty / energy vulnerability at consumer associations	*Action #1B* Home visits in the urban area by home care professionals
N/A	*Action #2* Home visits in the rural area by home care professionals
N/A	*Action #4* Help desk in rural areas by tele care professionals
N/A	*Action #5* Help desk advice through energy professional HEAs
Synergy #1 Help desks for consumers in poverty/vulnerability at third sector institutions	*Synergy #1* Barcelona Council
Synergy #2 Distribution of material at third-party events	*Synergy #2* Deputation of Barcelona and Maresme Council
N/A	*Synergy #4* Tele Care Organization
N/A	*Synergy #5* Energy cafes with PAES

Finally, the data collected from the households reached with the actions were analysed both in terms of energy consumption and quality of comfort level (as the value of energy savings in case of energy poor people is not indicative considering that in extreme cases people should increase their household energy consumption in order to fully satisfy their energy needs). The indicators specifically defined and used within the ASSIST project are "ASSIST Energy Savings Indicator (ESI)" and "Vulnerability Empowerment Factor (VEF)" [24].

The ASSIST ESI is given by the comparative sum of different indicators: the energy saving indicator, the comfort indicator, and the money saving. The *energy saving indicator* is based on the information on energy consumption collected considering which months the monitoring was ongoing, monthly electricity (in kWh) and heating fuel consumption (in kg or litres) rates, and the region of the monitored household; the *comfort indicator* is a weighing mechanism, based on qualitative perception analysis of the perceived comfort in the homes (in a scale from very uncomfortable to comfortable) and the *money saving indicator*, consisting of the weighted average of household expenditure on energy bills.

Moreover, to ensure that the more perceptual changes are taken into account, the ESI is considered jointly with the VEF. The VEF is an emotional and behavioural indicator measured both ex-ante and ex-post to be able to measure what the HEA visits have meant for the customer in relation to becoming a more conscious and empowered energy customer.

From the pilot conducted within the ASSIST project, it can be deduced that the professional role of the HEA is needed to identify, reach, and support consumers who are exposed or already in situations of energy poverty. Moreover, the results of the actions implemented by the operators after completing the training cycle were able to bring a real and quantifiable benefit in terms of savings in energy bills, increased consumer awareness and increased confidence in the role of the HEA.

Table 2. ASSIST Model results

Impact of HEA actions – Italy		Reference value
ASSIST Energy Savings Indicator (ESI)	**5.5%**	Percentage points calculated as the weighted sum of energy savings and comfort level increase and money saving
Vulnerability Empowerment Factor (VEF)	**0.4**	Scale from -3 to + 3, where +3 represents less vulnerability due to greater knowledge of the energy market and awareness of knowing where to seek help if necessary

6. TESTING THE ASSIST MODEL on summer energy poverty – COOLTORISE project

As briefly introduced in Section 1, 8the definition and general conception of energy poverty is changing, as a consequence of new issues emerging due to global warming and greater awareness of the needs of the most vulnerable.

Therefore, with the identification of the summer energy poverty, there is a willingness among researchers, social operators and entities interested in understanding and tackling the phenomenon, to test the validity of the ASSIST model also in the different scenarios of summer energy poverty.

This objective is at the heart of the Horizon2020 project *COOLtoRISE – Raising summer energy poverty awareness to reduce cooling needs*. The project aims to reduce summer energy poverty incidence among European households, improving their indoor thermal habitability conditions and reducing their energy needs during the hot season, thus decreasing the exposure to heat and heat-related health risks. This is achieved through the implementation of some soft measures to reduce the impact of the heat waves in low efficient households and to deliver tools and information both to householders and stakeholders to best mitigate summer energy poverty.

These actions, carried out in the context of social housing, will also be accompanied by more general awareness-raising actions on sustainability issues and the engagement of the inhabitants of the buildings involved, including requalification actions (e.g., the creation of communal gardens, both to mitigate the temperature and to encourage community life).

The study of the phenomenon and the implementation of appropriate actions will start with the design and training of an operator similar to the HEA, but capable of operating in the specific context of summer energy poverty: Summer Energy Poverty Agent (SEPA).

Within the project, COOLtoRISE partners will train SEPAs to implement actions aimed at supporting citizens in managing their energy consumption during summer (especially during heat waves) and to increase their comfort level (e.g., how to have a cooler environment without increasing energy consumption). Operators, coming from different sectors related to poverty and energy sectors, will develop technical skills on energy, sustainable development and energy saving by participating in *ad hoc* designed training courses especially tailored on the needs, national context, and role of future SEPAs.

For both the training strategy and the actions targeting families, the overall strategy will have a common project framework. However, as we will see below, the strategy for the implementation of activities will be defined at national level according to the social and geographical context in which the project is implemented.

Based on the experience acquired on ASSIST and on other similar projects, a drop-out rate of 30% may occur during the training phase. The drop-out rate might depend on the selection process of the volunteers as well as on their background (NGO, university students, etc.).

Finally, the table below (Table 3) shows, for each country, the number of SEPAs to be trained (assuming a dropout rate of 30%).

For each country a conservative (cons.) and optimistic (opt.) provision is presented.

Table 3. SEPAs to be trained (considering a 30% drop-out rate)

Country	Families to be involved		No. of SEPAs to be trained				Volunteers from the professional sector*	
	Cons.	Opt.	Volunteers		Coordinators		Cons.	Opt.
			Cons.	Opt.	Cons.	Opt.		
Bulgaria	1,000	1,500	67	100	4	7	40% - 40	40% - 60
Italy	650	815	43	54	3	4	90% - 4	90% - 5
Greece	600	750	40	50	3	3	10% - 36	10% - 45
Spain (MAD)	450	675	30	45	2	3	75% - 7	75% - 11
Spain (BCN)	400	550	26	37	2	2	50% - 13	50% - 18
Tot.	3,100	4,290	206	286	14	19	100	139
* The % indicates the expected percentage of voluntary agents from the professional sector.								

The table below (Table 4) shows the number of SEPAs to be involved, without considering a 30% drop-out rate. The table below shows, in detail for each country, the number of households and the number of SEPAs to be involved for training (no. of volunteers and coordinators) and the number of volunteers from the professional sector.

For each country a conservative (cons.) and optimistic (opt.) provision is presented.

Table 4. No. of SEPAs to be involved in training

Country	Families to be involved		No. of SEPAs to be trained				Volunteers from the professional sector*	
	Cons.	Opt.	Volunteers		Coordinators		Cons.	Opt.
			Cons.	Opt.	Cons.	Opt.		
Bulgaria	1,000	1,500	96	143	4	7	40% - 40	40% -60

Italy	650	815	61	77	3	4	90% - 58	90% - 73
Greece	600	750	57	71	3	3	10% - 6	10% - 7
Spain (MAD)	450	675	43	62	2	3	75% - 33	75% - 47
Spain (BCN)	400	550	37	52	2	2	50% - 19	50% - 25
Total	3,100	4,290	294	405	14	19	156	212
* The % indicates the expected percentage of voluntary agents from the professional sector.								

Regarding the content of the training course, the partnership intends both to build on the results achieved by ASSIST and to test new content and methodologies, including new and transversal topics and issues.

In detail, the COOLtoRISE training course is a 12-hour course based on the ASSIST-HEA training program. It is divided in various modules, such as the definition of the summer energy poverty phenomenon, its causes and consequences, cooling technologies and consumption, financial measures currently in place for the rehabilitation of buildings, available financing and a module totally dedicated to the communication tools and strategy, with the goal to foster the acquisition of the transversal skills, essential to build effective relationships and communication with the most vulnerable people.

However, the COOLtoRISE project foresees the development of five specific training courses, i.e., each country has adapted the general training course to its own social specific context. The general course has been built and presented by the training responsible; then it has been shared and approved by all the partners involved in the project.

For this reason, the country specific training is different from one country to the other, not only due to the social context that characterises the country but for the target to train too. In detail, in Bulgaria the target that will be reached is last year students in schools and their parents/relatives; in Greece the SEPAs will derive from various targets: members of local initiatives, active citizens, professionals and university students; in Italy *capiscala* (tenants of social houses) will be trained. The target in Spain (Barcelona and Madrid) are university students.

Concretely, the trained operators will organise raising - awareness activities for the most vulnerable households who are living in a situation of economic vulnerability. Operators will be supported and monitored by the coordinators - trained with a training course built ad hoc and foreseen by the project.

In conclusion, the COOLtoRISE project will develop two training courses: one for the volunteers/ operators and the other for the coordinators. Both the training courses will be adapted to the context and to the target as well as the method of delivery of the training course depends on the country's strategy. Moreover, the training courses will be supported by an online e-learning platform on 'Moodle' that partners can use or as a supportive platform for the participants (Greece, Bulgaria and Spain) or to deliver entire classes (Italy).

The activities of the project, that will be organised by the operators (SEPAs) will be held in summer, where the problem is clearer. This strategy will be followed in the second summer (June - September 2023) with the goal to reach a higher number of vulnerable householders.

7. Conclusions

The results gathered and presented have a twofold purpose: on one hand show the complexity of the energy poverty phenomenon, and its wide social implications, on the other hand present the research at European level on this regard. On the first aspect, it is important to note that the narrative about energy poverty is constantly evolving. From an initial broad and general conception of poverty, the more peculiar aspects of energy poverty are being defined and have now gained recognition also at the legislative level. Alongside the traditional measures of intervention, more in line with the broader conception of poverty, recently more specific measures based on direct contact and advice with the vulnerable citizens are being designed and implemented.

These new measures enable to address those aspects of energy poverty that are more difficult to grasp from a simple bill: such as the lack of well-being within the home [25], the resulting health problems [26], but also social isolation, stigma, and the difficulty of identifying competent operators [27]. On top of all this, there is the difficulty of people who often find themselves unprepared in front of the ever-changing energy market, from the choice of old and inefficient household appliances to suboptimal energy contracts.

The recognition of these new issues, together with the renewed commitment of European states to achieve a fair and inclusive transition to full decarbonisation, has led to increasing attention being paid to the phenomenon, although significant stigma or political inaction persist, especially at the local level. The presented research aims also at fostering political attention on these themes.

The results of the two concluded projects (SMART-UP and ASSIST) and the actions carried on within the COOLtoRISE project clearly show the success in the implementation of the ASSIST model, and how this model is able to respond also to the new emerging challenges. The possibility to adapt the role of the HEA to the summer energy poverty related situations is heartening, and an important and versatile tool for combating summer energy poverty.

The HEA and SEPA, especially when embedded in an active network and working to their full potential, can support the vulnerable subjects in different contexts. It is important to underline that they are a useful supportive tool for municipalities or social institutions to implement strategies with lasting positive impacts and an important perceived benefit factor for the population.

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kWh versus Euro – What is the most effective way to inform about efficient products?

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Abstract

Energy efficient products often have a higher purchase price than less efficient alternatives. However, the life cycle costs are often lower due to the lower operating costs. From a purely economic point of view, efficient appliances are not only more ecological but often also more economical and, accordingly, should be purchased more frequently than less efficient appliances. However, this is not always the case. Information deficits are one of the major reasons of this discrepancy: the purchase price is visible during the purchasing process, but the follow-up costs are not, at least not in their exact amount. The EU Energy Label can be considered as a solution to close this gap. During the past decades, there has been a discussion on whether it would be better to communicate the monetary costs associated with energy consumption, since their calculation by the consumer is difficult or needs a high level of cognitive effort.

In this study, experiments and field studies on a total of 19 product groups were evaluated with regard to the question of whether the indication of costs instead of physical units affects the decision-making process of the consumer. It has been assessed under which circumstances it might positively influence the purchase decision of the customer, i.e. helping him or her to arrive at a more “energy efficient” decision. Overall, the results indicate that monetary claims possibly exceed the effect of claims on a physical basis when the costs or the differences between the alternatives available seem “relevant” to the consumer.

Background and objective

Energy efficient products often have a higher purchase price than less efficient alternatives. However, the life cycle costs are often lower due to the lower operating costs. From a purely economic point of view, efficient appliances are not only more ecological but often also more economical for consumers and, accordingly, should actually be purchased more frequently than less efficient appliances. In reality, however, this is not always the case. For example, in Germany there has been stagnation in the market penetration of the best energy efficiency class ("A+++") for many product groups in recent years: The market share of A+++ refrigerators stagnated at 27 %, A+++ freezers at 35 % and A+++ tumble dryers at 43 % [1]. This discrepancy between the expectation corresponding to lower life cycle costs of particularly efficient appliances and the actual consumer behavior has long been discussed in the literature [2, 3].

Information deficits are seen as one of the major reasons of this discrepancy. This can be summarized as follows: the purchase price of efficient appliances is transparent and visible during the purchasing process, but the follow-up costs for electricity or water consumption are not, at least not in their exact amount, which is why they are not usually included in the decision-making process of consumers. To close such information gaps, labels, in addition to the product price, are appropriate tools [4]. Accordingly, the EU Energy Label can also be considered as such a solution to close this information gap. The absolute energy consumption is communicated with the help of physical units and thus cost-related product properties are made transparent to the consumer. In this way, the energy consumption and possibly also the associated costs can be included in the decision-making process.

During the past decades, there has been a discussion on whether it would be better to communicate the monetary costs associated with energy consumption, since the calculation by the consumer is not possible or only possible with a high level of cognitive effort [3, 5, 6]. The monetary costs would be easy to grasp and directly comparable to the purchase price. A recent contribution to this debate was published in 2019: Andor et al (2019) investigated the purchasing behavior for lamps in an experiment [7]. They were able to show that the willingness to pay for efficient lamps was significantly higher if the test participants were given information on life cycle cost. Information on the EU-Energy Label of the alternatives, on the other hand, had no effect.

Furthermore, the focus of the EU Energy Label is on the energy *efficiency* of the products, highlighted through the graphically very appealing presentation of the energy efficiency classes [8]. The level of *absolute* energy consumption, on the other hand, is perceived less. Due to the relative nature of the EU energy label, consumers tend to buy efficient but, e.g. in case of large appliances, still high absolute energy consumption. In addition, consumers lose reservations about product groups that typically have high absolute energy consumption when those products are classified as very efficient (e.g., freezers) [9, 10]. Communicating operating costs in monetary units is seen as a way to focus more attention on absolute consumption.

In this study, a comparative literature analysis was carried out. Experiments and field studies on a total of 19 product groups were evaluated with regard to the question of whether the indication of costs instead of physical units affects the decision-making process of the consumer. The question of whether the way costs are communicated has an influence on purchasing behavior, was also considered.

Material and Methods

Table 1 shows publications and projects which were identified as significant. Either experiments or field studies were conducted and published on the topic in various European countries with a total of 19 product groups. Table 1 provides an overview of the time period, the method used and the geographical scope of the studies as well as of the product groups taken into account.

Table 1. Overview of investigated studies

Study	Time period	Research method	Geographical scope	Product group considered
Kallbekken et al. 2012 [11]	before 2012	Field study	Norway	Fridge-freezers Tumble dryers
Heinzle 2012 [12]	before 2012	Choice-based conjoint (CBC) analysis	Germany	Television sets
DECC 2014 [13]	2013/14	Field study	Great Britain	Washer-dryers Washing machines Tumble dryers
Incent 2016 [14]	2014	Field study	Germany	Refrigerators and freezers Washing machines Dishwashers Tumble dryers
Andor et al. 2017 [15]	2015	Discrete choice experiment	Germany	Refrigerators
Conseed 2018 [16]	2017	Discrete choice experiment	Slovenia Greece Norway	Real estate (SI) Fridge-freezers (GR) Cars (NO)
Conseed 2019 [17]	2018	Field study	Ireland Spain	Real estates Washing machines Dishwashers Fridge-freezers
Andor et al. 2019 [7]	2018 (?)	Willingness-to-pay (WTP)-experiment	Germany	Lamps (CFL, LED)

Source: Own compilation

In the following, the analysed studies are briefly described.

Kallbekken et al. (2012) [11]

The aim of the field study was to test whether highlighting information on operating costs at the point of sale leads to more energy-efficient appliances being purchased on average.

The experiment was conducted in the six megastores of a Norwegian electrical appliance retail chain, selecting fridge-freezers and tumble dryers as objects of investigation. The other shops in the chain served as controls with their sales figures. Two interventions were implemented, tested both individually and in combination over a period of 5 months.

- Intervention 1: Label with lifetime operating costs (EU scheme with letters).
- Intervention 2: Training of sales staff (two-step training approach)

Heinzle (2012) [12]

The aim of the experimental study was to examine three formats for indicating energy consumption (physical units (watts), annual electricity costs and lifetime electricity costs) to see how effectively they influence consumers' interpretation of this information and subsequently their decision-making behaviour.

Hypothesis 1 states that the accuracy of the estimate of potential savings in electricity costs increases significantly when monetary rather than physical information on energy consumption is provided. From this it can be deduced what the effect of providing monetary values is: if the savings are underestimated on the basis of physical data, or if they are estimated correctly, the willingness to buy an energy-efficient appliance should increase when monetary data is given. If the savings are overestimated by means of the physical data provided, the willingness to buy an energy-efficient appliance should decrease when monetary data is given.

To test the hypothesis, first 248 people were randomly assigned to three groups that received different information (group 1: electricity consumption in watts, information on electricity price; group 2: electricity consumption in watts, no information on electricity prices, group 3: electricity consumption in euros). The people were asked to estimate the difference in electricity costs in euros.

Hypothesis 2 is derived from the result of study 1, i.e. that the difference is overestimated when watt figures are given: It is assumed that the WTP for a premium for more energy-efficient products will be greater when energy consumption is given in watts (i.e. that monetary specification is counterproductive). At the same time, it is assumed that this negative effect of specifying monetary costs in euros could be offset by specifying costs over the whole lifetime and not on a yearly basis (reverse pennies-a-day effect). Thus, according to hypothesis 3, the WTP for a premium for more energy-efficient products is assumed to be greater when energy consumption is reported as "lifetime operating costs" compared to "annual operating costs" or "watts".

To test hypotheses 2 and 3, a choice-based conjoint (CBC) analysis was conducted. The subjects were divided into 3 groups (group 1: physical information on energy consumption; group 2: information on lifetime electricity costs; group 3: information on annual electricity costs).

DECC (2014) [13]

The aim of the field study was to provide robust evidence on whether providing information on lifetime electricity costs at the point-of-sale changes purchasing behaviour by increasing the attractiveness of appliances with lower energy consumption. The study was conducted with washer-dryers, washing machines and tumble dryers.

Thirty-eight John Lewis shops across the UK were randomly assigned to one of the following two groups:

- Group 1, intervention (19 shops): The EU energy label also showed the cost of electricity over the lifetime of the appliance.
- Group 2, control (19 shops): Only the EU energy label was shown on the appliance, without the addition of the electricity costs.

It was ensured that the allocation of shops to the control or intervention group was similar in terms of key variables.

Training courses were conducted in July 2013 with a representative from the major electrical departments of almost all shops. Partners from control shops were given a basic overview of the study, while partners from intervention shops were provided with much more detailed information about the study and how running costs were calculated. Focus groups with shop representatives were conducted at three points in time to better understand what is happening at the point of sale.

Incent 2016 [14]

The aim of the field study was to explore the usefulness of awarding operating costs and potential effects both for consumers and for retailers.

In two electronics markets in Berlin, the operating costs over 10 years (useful life) were displayed on the device (simple and comprehensible calculation, e.g., no increase in electricity costs assumed). The experiment was conducted with fridge-freezers, washing machines, dishwashers and tumble dryers.

There were two variants:

- Label 1: Only operating costs over 10 years and
- Label 2: Operating costs and classification in scale to operating costs of appliances of the same "category".

In addition, information in the market was provided. The duration of the field study was 6 months.

Andor et al. 2017 [15]

The aim of the experimental study was to identify the influence of the type and amount of information ("stimuli") in the context of the energy label on consumers' choices. Does a lot of information lead to heuristic decisions, i.e. to making a decision only on the basis of the energy efficiency class?

The households involved were divided into three groups. Households in the control group received the information on the refrigerators in the form of a simplified EU energy label which only displayed the annual electricity consumption and the energy efficiency class. Households in the *Operating Costs* group received information on annual running costs in addition to the simplified label. Households in the *Competing Stimuli* group received, in addition to the simplified label and the annual running costs, information on other, non-energy-related appliance features acting as additional stimuli and compete for attention.

Households in the three groups were faced with four choice situations, each comprising two choices (A and B). The choice situations M1 and M2 reflected realistic decision situations, while S1 and S1 did not correspond to real market situations.

Conseed 2018 [16]

The aim of the experimental study was to investigate whether the provision of monetary energy information in addition to the EU energy label can convince consumers to buy more energy-efficient products as compared to the situation in which only the EU energy label was given.

Three discrete choice experiments were conducted:

- Real estate in Slovenia (two groups): control group: label only and treatment group: indication of the annual energy costs in addition to the mandatory energy label.
- Refrigerators in Greece (four groups): with label (control group), with label and indication of annual energy costs (treatment 1), without label + non-monetary information (treatment 2), without label + indication of annual energy costs (treatment 3).
- Cars in Norway (two groups): control group: label only and treatment group: monthly energy costs in addition to the mandatory energy label.

Conseed 2019 [17]

The aim of the field study was to investigate whether the provision of monetary energy information, in addition to the EU energy label, can convince consumers to buy more energy-efficient products compared to the situation in which only the EU energy label was given.

Three field tests were carried out:

- Real estate in Ireland. Additional information: annual energy costs.
- Household appliances in Spain (washing machines, dishwashers, fridge-freezers). Additional indication: monetary savings over the lifetime of the appliances. There were three interventions: 1)

additional label with savings only, 2) training of sales staff only, 3) combination of label and training. Comparison of experimental and control markets.

- Cars in Norway. The treatment consisted of three elements: operating cost label (monthly operating costs), online calculation tool, training of sales staff.

Andor et al. 2019 [7]

The aim of the experimental study was to determine consumers' WTP for more energy-efficient lamps based on different information.

The study comprised four steps: The test participants were first given general information about the technical properties of CFL (compact fluorescent lamps) and LED lamps. In the second step, they had to choose 15 times from a list between two different energy-efficient lamps with different prices. After a first decision run, the test participants were divided into three groups which received different information:

- Group A received information about life cycle costs (purchase and operating costs) and corresponding explanations,
- Group B was explained the energy label and saw the actual energy label of the two alternative lamps.
- Group C received information that was irrelevant for the decision (development of lamp sales in Germany); (control group)

After having informed the participants, a second round of decisions took place, in which the test participants again had to make a choice, in total 15 times, from a list between two different energy-efficient lamps with different prices.

The studies were evaluated with respect to the following criteria:

- Assessment method
- Products considered
- Temporal framing of the cost data (annually, over a longer period or the entire product lifetime)
- Was it possible to determine a positive influence of monetary claims on the purchase decision of consumers regarding particularly efficient products?

Results

Experiments vs. field studies

Experiments (concrete choice, willingness-to-pay, choice-based conjoint analysis) more frequently show a positive effect than field studies under real conditions.

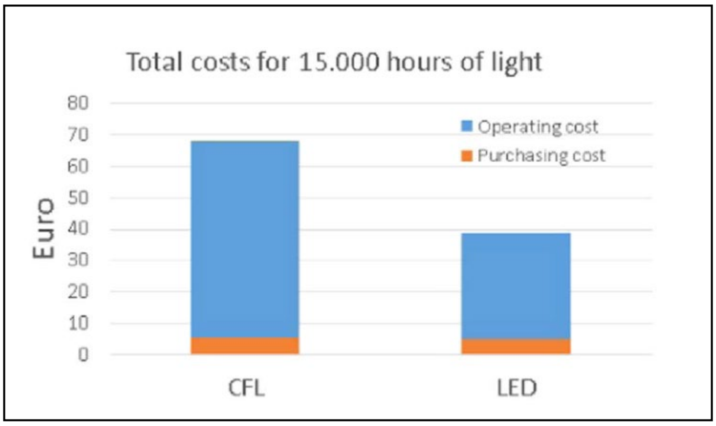
- Of seven experiments conducted (the studies cover several experiments or variations thereof), a positive effect was found in five (83 %).
- In the 13 field studies conducted (also the field studies cover several variations or product groups each), a positive effect was found six times (46 %). This was sometimes less significant and once only visible if the sales staff were appropriately trained. In seven cases (54 %), no positive effect of monetary information was found.

This effect can be attributed to various causes. On the one hand, social desirability has been discussed for a long time to be a possible contributing cause of people's survey responses regarding environmental actions. In this case, this means that the willingness to buy a particularly efficient product may be overestimated in surveys. The effects of social desirability seem to be small and subtle but may be heterogeneous across studies [18]. On the other hand, interfering effects can play a decisive role in field studies, e.g. special promotions, a lot of competing information, delivery problems, etc. In addition, the definition of a control situation (control market or control period without intervention) is challenging, since other markets may have a different customer composition, or the general conditions may change in time [e.g. in 11]. Furthermore, compared to real-world settings, a stylized decision environment – like in a discrete-choice experiment on energy efficiency – may induce participants to focus more strongly on the energy label and increase the overall rate of opting for a more energy-efficient appliance [15].

Share of operating costs in total costs

Monetary information is particularly effective when the share of operating costs in total costs is relatively large. For example, there is a significant increase in willingness-to-pay for monetary claims compared to energy efficiency labeling information in [7]. With total costs ranging from about 39 to 68 euros, the initial cost only accounts for about 5 euros (+/- 7 euros price difference between lamps) – correspondingly, the operating cost is about 90 % of the total cost (see figure 1). Also, in [13] there is an effect of monetary data for washer-dryers, but not for washing machines. The authors suggest that the effect was observed for washer-dryers because their lifetime electricity costs were the highest of all the product types considered, making them a salient feature for consumers.

Figure 1. Total costs for 15.000 hours of light



Source: [7]

Absolute level of operating costs

Monetary claims have a positive effect on absolutely high operating costs. Both experiments [16] and a field study [17] showed, that for products with high operating costs the willingness to buy products with lower energy consumption increases when information on operating costs is provided compared to showing the physical units. For example, in [16], a discrete choice experiment was conducted for each of three product groups. For real estate and cars, there was found a significant increase in willingness-to-pay for energy-efficient alternatives: For cars (Norway), already monthly fuel costs were reported to be in the three-digit euro range per month. For real estate (Slovenia), the annual energy costs were given. For fridge-freezers, with rather low level of operating costs, no effect was visible (see following table). For real estate, also the difference between operating costs was very significant (see also the following chapter).

Table 2. Overview of differences in operating costs for three product types

Geographical scope	Considered products	Temporal framing	Difference in operating costs	Positive effect of monetary information?
Norway	Cars	Monthly	1.500 vs 1.125 Norwegian kroner per month, equivalent to about 150 vs. 110 € / month	Yes

			Purchase prices: *400.000 vs. 450.000 kroner*	
Slovenia	Real estates	Annual	1640 € vs. 70 € / year *Purchase prices:* *88.000 vs. 96.000 Euros*	Yes
Greece	Fridge-freezers	Annual	44 € vs. 23 € / year *Purchase prices:* *550 vs. 600 €*	No

Source: [16]

In [17], different product groups were tested in a field study. For real estate (Ireland), providing cost information had a significant positive effect; for household appliances (Spain; washing machines, dishwashers, fridge-freezers), no or only a small effect was visible. The cost information for real estate was in the mid three- to four-digit euro range per year, while the cost information for household appliances was given over the lifetime and was in the lower three-digit range.

Differences between operating costs

Monetary data have a positive effect if the differences between the operating costs are high. This can be observed, for example, in the real estate example in [16]: high annual energy costs of 1640 euros were compared to much lower energy costs of 70 euros (see table 2). Also, in [7], the differences in operating costs of the shown lamps are relatively large with about 34 vs. 63 Euros over a useful life of 15,000 hours. (see figure 1)

In the case the difference is rather small, possibly smaller than consumers estimate based on the different energy consumption or energy efficiency classes, monetary information can even have a negative impact. For example, it was shown in [12] that consumers estimate differences in operating costs to be higher than they actually are when they only have information on energy efficiency class or energy consumption available. The actual cost differences were smaller than estimated by consumers, so that the willingness-to-pay was lower with additional information on (annual) operating costs.

Temporal framing of operating costs

Reporting lifetime operating costs tends to be more effective than reporting annual costs. For example, it was shown in [12] that indicating the annual electricity costs of televisions is even counterproductive (cf. previous chapter), i.e., it leads to a lower willingness to pay than information in watts. However, specifying the electricity costs over the entire lifetime of the appliances leads to a higher willingness to pay, both compared to specifications in watts and compared to specifying the annual electricity costs (see figure 2). Adding up the annual costs over a longer period of time increases the amount of operating costs, both in absolute terms and in comparison to the purchase price. In some cases, the annual operating costs are too low, and subjectively do not matter ("pennies-a-day effect", see [19]). In the field studies with data on service life, nevertheless, no or only a small effect is visible. This can have various causes, e.g. competing information, special promotions or difficulties in defining the comparison group (cf. chapter “Experiments vs. field studies” above).

Figure 2: Comparison of willingness-to-pay with different specifications of energy consumption / operating costs (in

	Group 1 ("watts")	Group 2 ("lifetime energy operating costs")	Group 3 ("annual energy operating costs")
Energy consumption/energy operating costs	60 W	€180	€18
	115 W	€340	€34
	170 W	€500	€50
	225 W	€660	€66
WTP:	480 €	640 €	350 €

"watts", lifetime or annual energy operating costs)

Source: Own compilation with data from [12]

Competing information reduces the effect of monetary disclosure

In [15], the effect of competing information on the effectiveness of cost information was investigated. When energy costs were shown in addition to the EU Energy Label in a simplified setting, households were significantly more likely to choose the more energy-efficient appliance. If, on the other hand, additional information on other, non-energy-related appliance features acting as additional stimuli and competing for attention, was displayed, there was no effect or even a negative effect of energy costs compared to information in kilowatt hours.

Further findings

Besides the above-described results there were some further findings which are of interest:

- When there is an effect of monetary claims for household appliances, it is usually rather small [13, 17]. The large effect in [7] is likely due to a combination of effects: it is an experiment (not a field study), the operating costs are a large proportion of the total costs and the differences between the operating costs of the alternatives are relatively large. In addition, the informative value of the efficiency classes shown is rather low: A vs. A+ on a scale from A++ to E.
- In contrast, the effect of monetary information for real estate and cars is rather large [16, 17].
- Training of sales staff only partially increases the effect of the label (positive effect in [13], no effect visible in [17]),
- Reporting savings might have a stronger impact than reporting (absolute) costs [17],
- Women seem to be more responsive to energy-use information and also cost information [16].
-

Discussion and conclusions

The results indicate that monetary claims are effective, and possibly exceed the effect of claims on a physical basis, especially in those cases in which costs or the differences between the alternatives available reach such a high level that it is substantial enough to be "relevant" to the consumer: this can be caused by a high share of operating costs in total costs, by a large absolute level of operating costs, or by large differences between alternatives. Depending on how high the operating costs are in absolute or relative terms compared to the acquisition costs, sometimes information on a monthly or annual basis is sufficient for this (e.g. for real estate or cars) – sometimes, however, only information over a longer period of time leads to the perception that the operating costs are of a relevant order of magnitude (e.g. for televisions). These results are in good agreement with the conclusions in [20], where requirements for the communication of life cycle or operating costs were derived, taking into account behavioural economics.

If the absolute values or the differences, especially in comparison to purchase prices, are rather small, monetary information can even be counterproductive: because it decreases the relevance of operating costs estimated by consumers with the help of energy efficiency classes and the indication of energy consumption. Communicating the costs objectifies the decision-making process here – but since the differences were previously overestimated, the effect works in the other (wrong) direction.

Overall, the results tend to suggest that monetary information should not generally replace information in watts or kilowatt-hours on the energy label, since a potentially small advantage is counterbalanced by the risk that the information will not influence behavior in the desired direction. There are also practical limitations: for example, electricity prices in different Member States range from around 30 ct/kWh in Germany to just under 10 ct/kWh in Bulgaria [21]. Thus, a uniform value for all member states would be poorly representative.

However, targeted use in specific applications and situations can be useful: for example, national communication activities could certainly draw attention to operating costs and differences if the conditions are right. In [22] retailers saw an increase in sales of efficient appliances (A++ and A+++) due to the indication of annual operating costs. In addition to real estate and cars, for which the studies did indeed find a significant effect, there are also household appliances for which the differences in operating costs are (still) high, for example tumble dryers [23]. It can be assumed that the operating costs for heating systems are also large enough to argue with.

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The usefulness of sales data to understand energy stakes for appliances

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Abstract

Knowing the market is key for deciding on energy label classes' thresholds, minimum energy performance standards (MEPS) and revisions of these policies. The EPREL database has started to operate but in the absence of sales data, will it fulfil one of its purpose, i.e. to provide the Commission with up-to-date energy efficiency information for products for reviewing energy labels?

Our paper demonstrates the potential of systematic market monitoring based on sales data. In a report published in March 2021, updating a previous report published in 2017, comprehensive sales data from GfK is analysed for refrigerators, washing machines and tumble driers. The data covers the years 2004 – 2019 and the national markets of France, Germany, Italy, and for the whole EU market. It includes information on sales per energy efficiency class, average energy consumption, size and price.

The results show that the efficiency of refrigerators has improved by 40% since 2004. The energy consumption, however, has decreased less than that. For washing machines, large drums confirm their popularity, in part because high efficiency is strongly linked to large drums. Considering the low efficiency of small partial loads, the calculated energy and cost savings are up for discussion. Heat pump tumble driers have continued to extend their popularity among consumers: this energy-efficient technology made up nearly 60% of all drier sales in the EU in 2019. On national markets, their sales share can be even higher. A ban of non-heat-pump models could save Europe around 8 TWh per year. The results further show large differences between national markets – even though the same regulatory framework applies in all EU Member States, and the same international manufacturers dominate most markets.

1. Regular monitoring of the market would be of great benefit to Europe

Energy labels and minimum energy performance standards (MEPS) for energy-related products are crucial policy measures that accompany the ongoing market transformation towards increased energy efficiency and reduced energy consumption. Appropriate thresholds for energy label classes and their link to MEPS thresholds are essential for the effectiveness of these instruments. When most models are already in the best class of the label and MEPS levels are undemanding, innovations can be delayed. This was the case for example for washing machines in Europe between 2013 and 2020.

Ambitious energy performance classes, for which there are no products yet (but presumably are technically achievable in the medium term), stimulate the market ("market pull"), and demanding MEPS levels raise the efficiency level of the least efficient appliances ("market push"). Together, these two policy tools ensure continuous performance improvement (see the example of refrigerators in the previous market monitoring report ([1] Michel, Attali, Bush, 2016).

In order to define effective policy and programme measures, it is essential to understand the market - what products are being purchased and what are their characteristics, including energy performance. Indeed, understanding the market gives policy makers the ability to make informed decisions about the optimal level of new MEPS and energy class thresholds on labels, and how to plan for them. If sales data are available over a long period of time, it is possible to develop statistical models of the installed base to estimate trends in energy consumption and other parameters ([2] Attali, Bush, 2013). These models can be used to assess past savings from previous measures, but also to estimate future savings from proposed new policies (see the Australian example for refrigerators: ([3] Harrington, Lane, 2010).

Many developed countries and emerging economies have a market monitoring system for products labelled or regulated by MEPS or energy labels. It is based either on sales figures obtained from specialised companies or manufacturers, or on information on models placed on the market, which must be registered in a database ([4] Michel, Attali, Bush, 2014). In the past, Australia even used its register with the detailed characteristics of each model to cross-match with model sales data ([5] Michel, Harrington, 2015). To date, Europe does not regularly monitor the market with sales data ([2] Attali, Bush, 2013). When the European Commission needs information about markets and products in order to establish future regulations, the available data are compiled by consultants during preparatory studies or impact assessments. The problem with this data, which is often provided by industry, is that it is incomplete, often outdated and cannot be compared over time or between countries. Without sufficient information on real market trends, it is difficult for European policy makers to launch timely policy revisions and to set label classes and MEPS levels at an optimal level.

The latest framework regulation on product labelling (EC, 2017/1369) has foreseen the creation of a database for products covered by the energy label: suppliers - be they manufacturers or distributors - have to register all products placed on the European market with their technical data but also documents useful for market control authorities (who have restricted and specific access for these elements that are not public).

This database - "EPREL - European Product Database for Energy Labelling" - has three official objectives:

- support the market surveillance authorities in the performance of their tasks
- provide the public with information on products placed on the market and their energy labels, as well as product information sheets
- provide the Commission with up-to-date information on the energy efficiency of products for the review of energy labels

Although the process of creating the database has been delayed, EPREL is now operational. However, it can be observed that, while market surveillance authorities will indeed be able to rely on EPREL for part of their work, it is unlikely that the other two objectives will be achieved (or at least without substantial change, or the development of additional digital tools). Indeed, as it has been constructed, EPREL does not allow the user to know if appliances are really on the market, or if they are still on the market, and on which national market they are available - the "European consumer" is in fact "national" and it will be impossible for a French consumer, for example, to filter the offer available in his country. As sales data is not collected, even in aggregate, EPREL will not provide a sound basis for reviewing regulations (international experience shows, for example, that even for databases that charge for registration of each device, a significant percentage of models are never sold ([6] Michel, Jones 2015).

Sales data, as presented in this report, is therefore an essential complement to the information provided by the EPREL database. It will be several months before EPREL produces full analyses, but the sales data can be purchased now.

2. Market monitoring study

ADEME (French Agency for Ecological transition) regularly funds studies on white goods market monitoring, demonstrating the value of systematic market monitoring, based on robust sales data (recent, complete and consistent over time). This paper presents the latest study (published in March 2021), i.e. the results of the analyses for refrigerators, washing machines and dryers in Europe as a whole as well as France, Germany and Italy, for the period 2004-2019.

After introducing the methodology and data structure, a summary of the results is presented, first per product, and then per country. In order to bring as much information as possible in this paper which length is limited, and since it is interesting to underline the cross references between the 2 types of results (showing differences depending on products and differences hiding behind the European averages), the figures have been grouped.

2.1 Data and Methodology

The authors acquired sales data for domestic refrigerators, washing machines and tumble dryers from GfK. GfK is a leading market research company operating in many countries around the world. In Europe, GfK monitors around 90% of the white goods markets and the 27 Member States (23 for tumble dryers) plus the UK. Sales data and many product characteristics are obtained by GfK from retailers.

For this study, GFK provided for each energy efficiency class (A++ to G[257]) the sales, the sales-weighted average energy consumption, the size and for washing machines, the water consumption, and the average

[257] For refrigerators and washing machines, the label classes analysed in this paper are based on label previous to 2021

prices. This information is based on declarations made according to the energy label regulations, with the exception of product prices. The data is aggregated and does not contain information on brands or models. These aggregated data have been acquired for the EU-21[258], as well as at national level for France, Germany and Italy. The years covered are 2004 to 2019.

2.2 Taking the economic situation into account

The sale of consumer products and their prices can be strongly influenced by the economic situation. When interpreting the data, readers should bear in mind that within the period covered in the study, 2004 - 2019, there have been periods of financial and economic turmoil in Europe. Countries have been hit at different times, and not always with the same intensity. Purchasing power, which is specific to each country, has also changed over time. These variations are not reflected in the EU averages, although a general decline in sales can be observed between 2008 and 2010. The study covers the period up to 2019, the last year with available data. The impact of COVID-19 and the subsequent recession are therefore not visible in the analysis.

3. Results and discussion

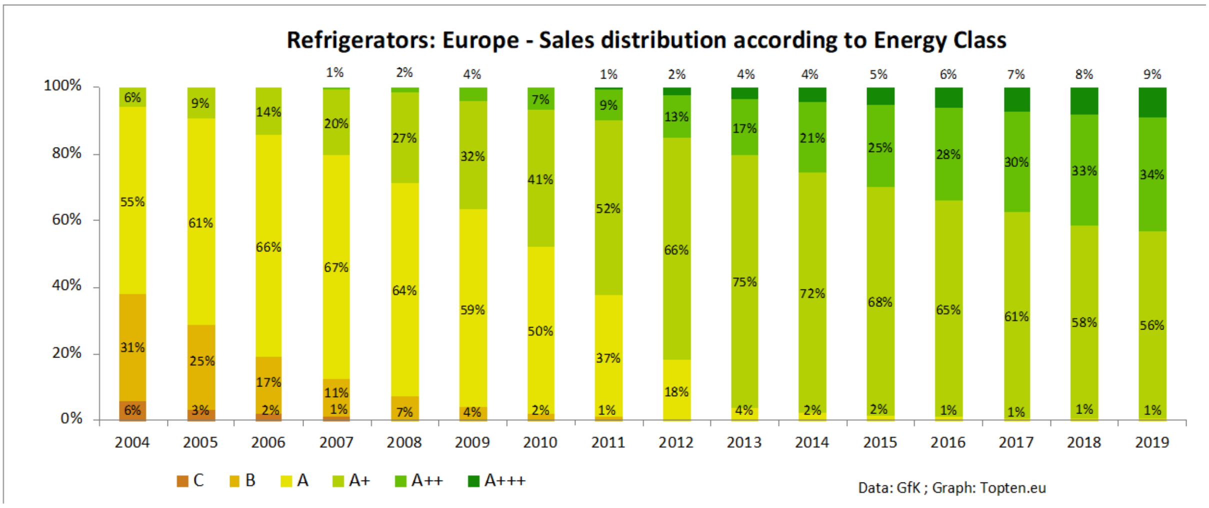
3.1 The European market

Over the last 15 years, the markets for refrigerators, washing machines and tumble dryers have become more energy efficient, in terms of the distribution of sales according to energy label classes. The speed at which energy efficiency is improving has slowed down in recent years. These changes can be interpreted differently for the three product categories.

3.1.1 Refrigerators

The European refrigerator market has steadily improved in terms of energy efficiency between 2004 and 2019. During that period, the average energy consumption fell by 27% despite a remarkable increase in unit volume of around 9%. In France, the market shares of very energy efficient refrigerators are lower than for the European average; in Germany and Italy, on the contrary, efficient refrigerators are sold more than the European average (8.9% of sales in A+++ in 2019 in Europe, 19.7% in Germany, 12.2% in Italy and only 1.9% in France). Italy has the highest reported average energy consumption, as Italians prefer relatively large and less efficient refrigerators. The Germans, on the other hand, prefer smaller, more efficient refrigerators, with lower energy consumption. New, more demanding MEPS apply since March 2021, as well as a new energy label with an A to G scale and more stringent thresholds. The European Commission estimates that these measures will generate savings of 10 TWh of electricity per year in 2030.

Figure 1. Refrigerators: 40% improvement of the Energy Efficiency Index



258 Only countries covered by GfK since 2004 were taken into account: AT, BE, CZ, DE, DK, ES, FI, FR, GB, GR, HR, HU, IE, IT, NL, PL, PT, RO, SE, SI, SK

Figure 2. Refrigerators: 27% improvement, i.e. reduction of kWh

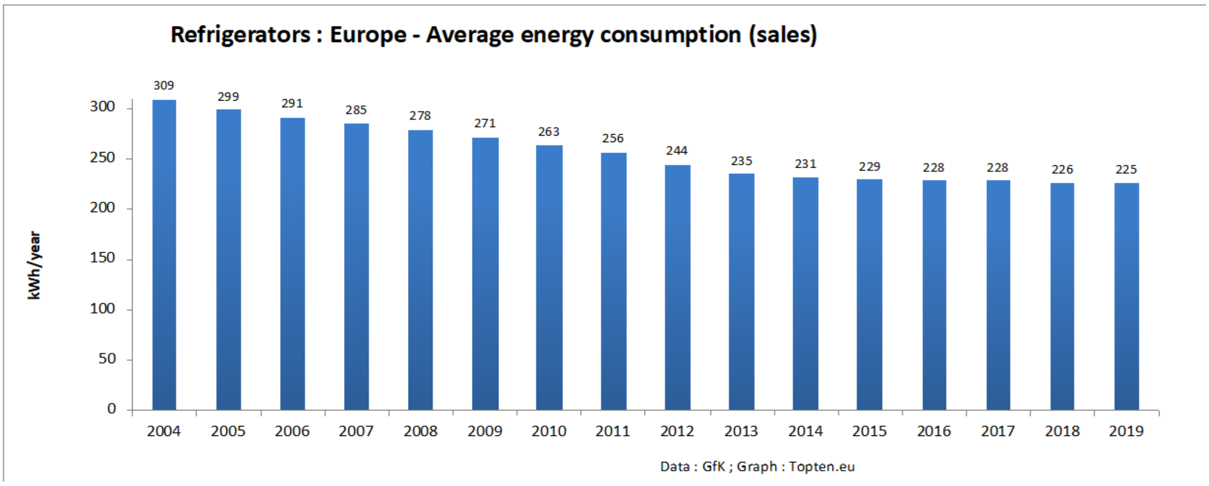
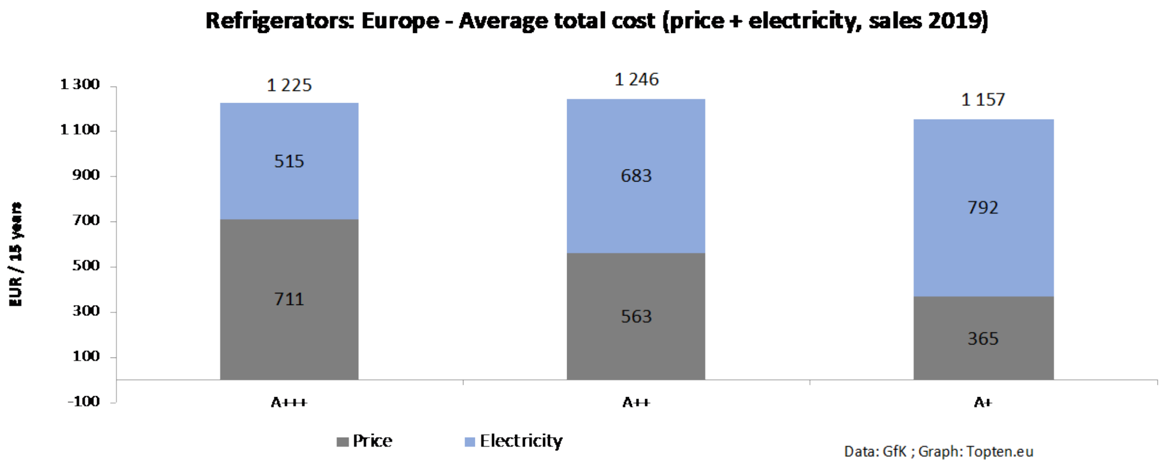


Figure 3. Refrigerators' efficiency: always good for the planet, may be neutral for the wallet



3.1.2 Washing machines

For washing machines, the highest energy efficiency classes have been very well accepted by the market since the introduction of a revised energy label in 2013: A+++ models represent 81.5% of sales in Europe in 2019, with differences between European countries: 70.5% of models sold in France are A+++ ; 81.4% in Italy ; and 92.4% in Germany). Average energy consumption has also fallen in Europe despite a trend towards larger capacities. However, energy consumption is starting to stagnate, for lack of a label that really encourages innovation. Average water consumption has also stalled, or even slightly increased, in Europe in recent years. The main reason is that higher-rated washing machines use more water because they tend to be larger. The trend towards large models observed in previous years is still relevant: higher energy efficiency of washing machines translates into large capacities, rather than lower energy consumption (in 2010, 66% of sold models were ≤6 kilos, this dopped to 23% in 2019). New, more ambitious MEPS apply since March 2021, as well as a new energy label with an A to G scale and more stringent thresholds. The European Commission estimates that these measures will generate savings of 2.5 TWh of electricity and 700 million m^3 of water.

Figure 4. Washing machines: showing the need for a revision of the energy label

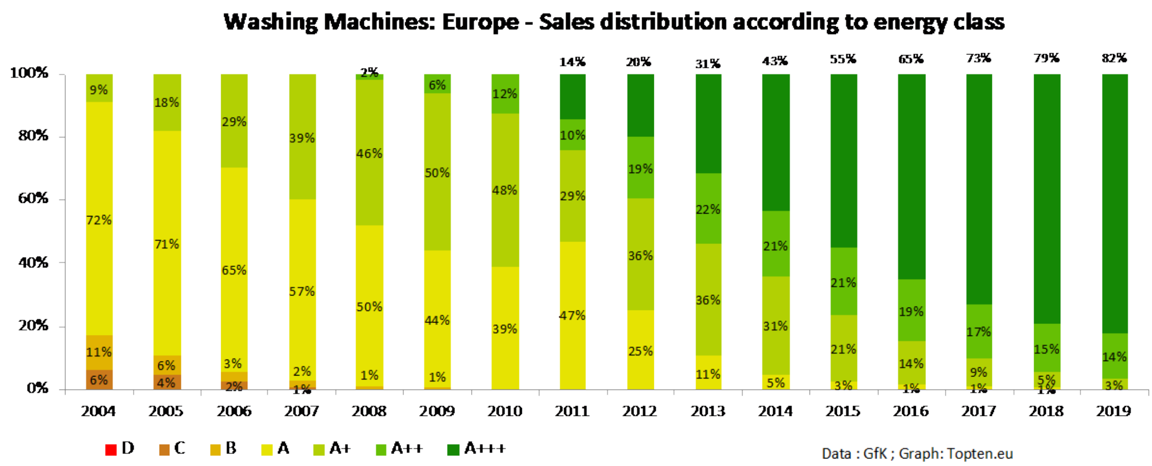


Figure 5. Very small differences between classes, partly explained by the fact that best classes are bigger

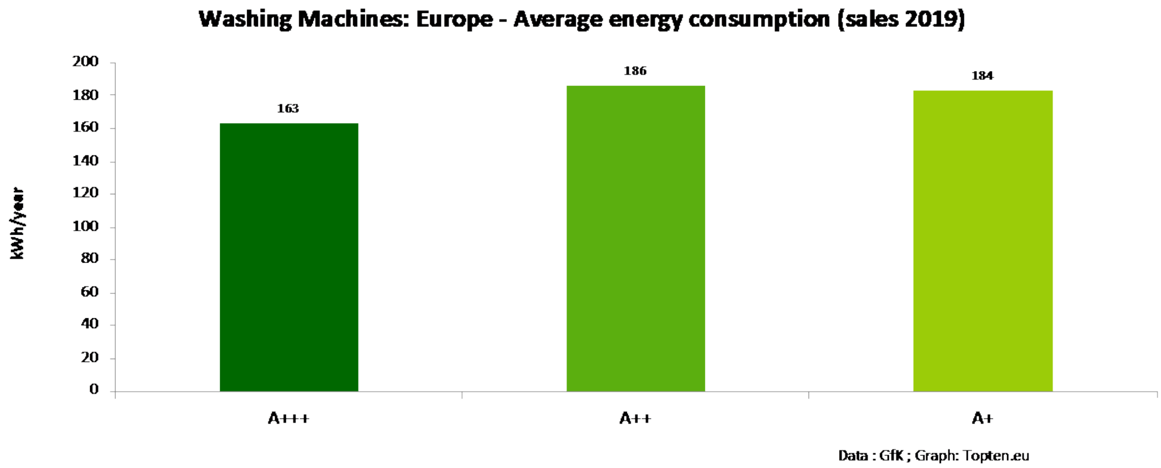
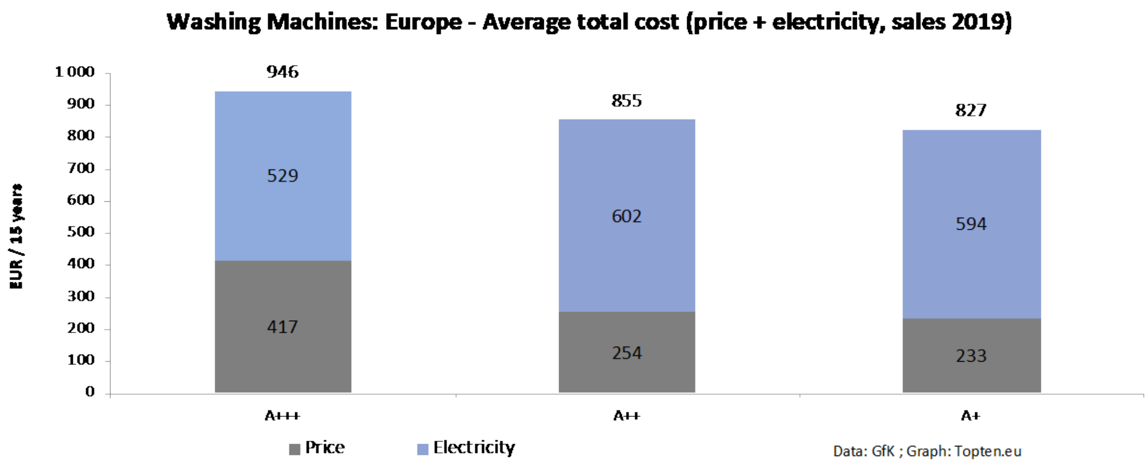


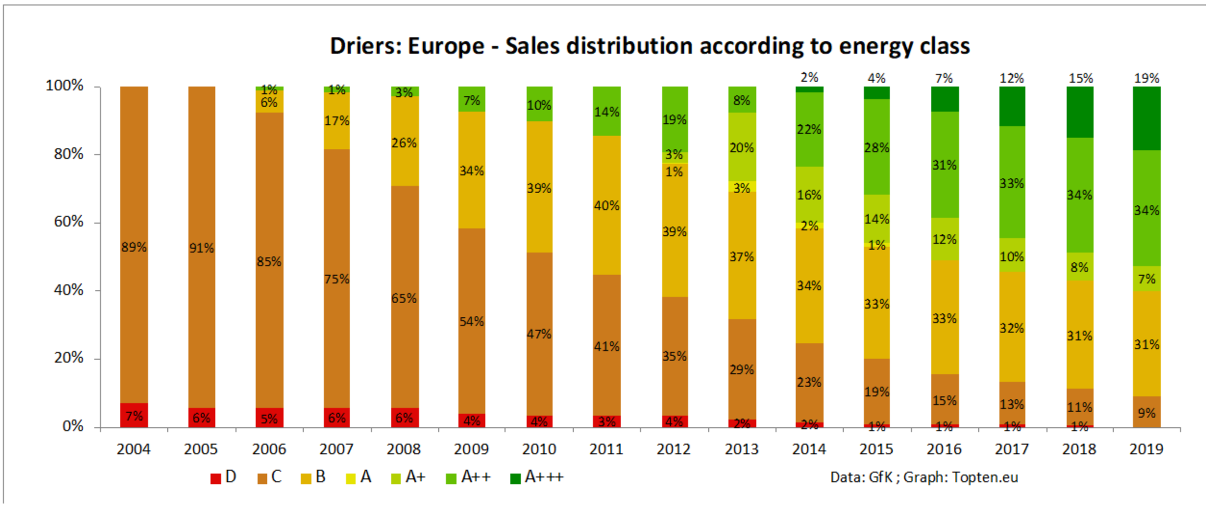
Figure 6. Washing machines' efficiency: always good for the planet, bad for the wallet



3.1.3 Tumble driers

Sales figures for tumble dryers still follow the positive trend observed in 2015: heat pump dryers (generally rated A+ and better) represent 59.5% of sales in Europe in 2019, 82.9% in Germany and 98.1% in Italy. In France, heat pump dryers only represent 37.7% of sales. This low figure for France translates into a much higher average energy consumption for tumble dryers sold in France (67% higher than Germany and 84% more than Italy). Over their lifetime, heat pump dryers generate a significantly lower total cost to the consumer. The potential energy savings resulting from a future MEPS which would ban the marketing of dryers without heat pumps would be 8 TWh/year in Europe, and 1.6 TWh/year in France. Information campaigns or rebates would be necessary to reduce sales of the less efficient models.

Figure 7. Driers – A decade of real progress thanks to heat pump models (from A+ and up)[259]



[259] Class A has a very low market share and there are almost no models in this class. Therefore, the results for class A are not statistically significant

Figure 8. Large consumption differences between energy classes (even when best classes are bigger)[260]

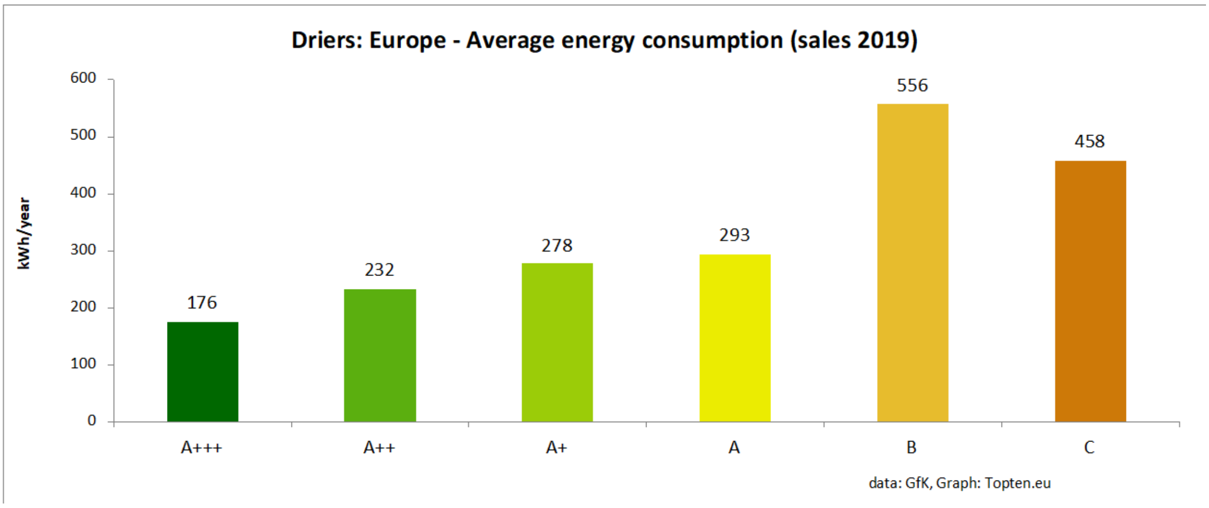
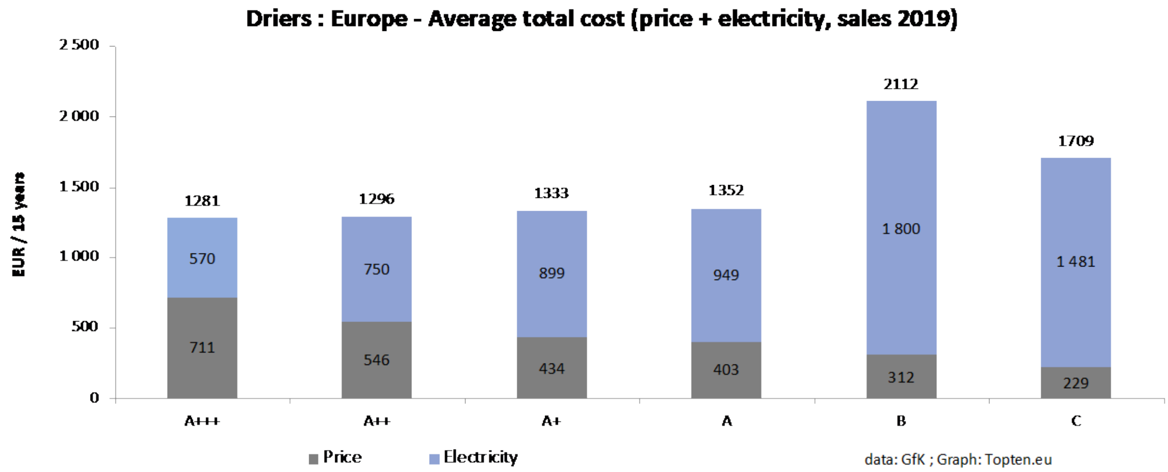


Figure 9. Driers' efficiency: good for the planet and good for the wallet[261]



3.2. National markets

The study also shows that national markets can be very different, while the same regulatory framework applies to all EU countries and the same international manufacturers dominate most markets.

3.2.1 France

Products sold in France were less energy efficient than those sold on average in Europe, for all three product categories studied. This confirms the findings of our latest market monitoring ([1] Michel, Attali, Bush, 2016), as well as the findings of a 2012 study that found more highly efficient products sold in Germany than in France ([7] SOWATT, Enerdata, 2012). Also in Italy, more efficient products are sold than in France.

[260, 4] Class A has a very low market share and there are almost no models in this class. Therefore, the results for class A are not statistically significant

Refrigerators, washing machines and tumble dryers sold in France consume on average more energy than those sold in the other two countries and in Europe. Only Italian refrigerators consume more, probably because they are larger. It is striking that the average prices paid by French consumers for new appliances are significantly lower than in Germany, Italy and the European average.

High-performance refrigerator models (A++, A+++) are more expensive than the European average and have a small market share. Refrigerators are slightly larger than the European average but the freezer compartment, which has a greater impact on energy consumption, is smaller. One explanation for the low prices for refrigerators is the relatively higher market shares of private labels with entry-level marketing.

In the case of washing machines, prices are close to the European average, with lower prices for the least efficient classes. This could partly explain why efficient washing machines are not very popular in France. The French preference for small capacity machines (6 and 7 kg) could also explain this low energy performance (as efficient washing machines are often larger).

The same pattern can be observed for tumble dryers: in 2019 only 38% of tumble dryers sold were equipped with a heat pump and the average energy consumption is 25% higher than the European average. Class B was the most purchased in 2019. This was already the case in 2015, and is therefore probably not the result of the C class ban in November 2015. The C class, even if banned, still accounts for 14% of sales in 2019. This is both an ecological and an economic concern, as consumers who do not choose a high-performance dryer end up paying a considerable total cost.

High prices for high performance products in the French market have been found ([8] Toulouse, 2015) when comparing prices of Topten products in France, Germany and Switzerland. When trying to correlate the price level and the preference for the most economical classes in Germany and Italy, it is found that high average prices for a class do not prevent consumers from buying models in that class. It therefore seems likely that French consumers are mainly focused on buying cheap products: not very economical, not too big and with a low purchase price. Additional information on the total cost of the products could be an incentive to choose products with a higher energy performance. Tumble dryers might be the best product category to test such a campaign: the potential for energy and total cost savings for consumers is very high.

3.2.2 Germany

The German market is characterised by high market shares for energy efficient products. The data presented here confirms that German consumers buy more highly energy efficient and quality products and are willing to pay more for them; more expensive than consumers in other countries (this has already been shown by ([1] Attali, Bush, Michel in 2009 and 2016)). Regarding refrigerators, the average EEI in Germany is clearly better than the European one (33 vs. 37 for Europe) and the average energy consumption of German refrigerators is 26% lower than the European average. This is related to the German preference for relatively small refrigerators, and probably to prices: average prices per energy class are lower than the European average for the more efficient classes, and higher for the less efficient classes.

92% of washing machines sold in Germany were rated A+++ in 2019, even with an average price for this energy class (and for that of the A++ class) visibly higher than the European average price. German consumers have a preference for 7 kg and 8 kg machines. The average declared consumption is 5% lower than the EU average.

Tumble dryers are generally very popular in Germany and sales are relatively higher than in France, Italy or the European average. This is probably partly due to the colder climate in Germany, which makes it difficult to dry clothes outdoors for long periods.

Since dryer sales are higher in Germany than in France, Italy and Europe on average, it is all the more welcome that German consumers are buying very energy efficient models: heat pump dryers account for 83% of sales in 2019. However, the 17% of dryers in class C and B account for 35% of the electricity consumption of dryers sold in 2019. Therefore, a ban on dryers without heat pumps would save energy even in Germany. As with refrigerators, the average price of the preferred classes (A++, A+) is below the price level in the EU, but the high sales in these classes make the total average price of tumble dryers higher than the European average.

3.2.3 Italy

The Italian market for white goods seems to be quite particular. Italian consumers buy refrigerators and washing machines with high energy efficiency similar to the average European consumer, while for tumble dryers, heat pump models are extremely popular (98% of sales).

As far as refrigerators are concerned, Italians also prefer larger models. The combination of rather large refrigerators with below average energy efficiency results in an average consumption 12% higher than in the European Union. The price level of Italian refrigerators is high compared to the European average. This could be explained by a fragmented retail market, with few sales in discount shops or on the Internet, but also by the preference for large models.

As far as washing machines are concerned, the opposite is true: prices are lower than the European average whether one considers the average total price or the average price per energy class. The energy performance and capacities of Italian washing machines are similar to the European average, resulting in an average energy consumption similar to that of the EU.

For tumble dryers, as mentioned above, the Italian market is very energy efficient. Compared to Germany and France, probably due to climate reasons, sales are lower in Italy. However, tumble dryers are becoming more and more popular and sales are increasing rapidly. It is therefore very positive that energy efficient tumble dryers are achieving very good sales rates in Italy. The most popular class, A++, accounts for 52% of sales. The average price of A++ and A+++ classes is slightly lower than the European average. But because the more efficient classes are more expensive than the less efficient ones, the average prices for all Italian tumble dryers are 17% higher than the European average.

Figure 10. Refrigerators: National differences in average energy consumption

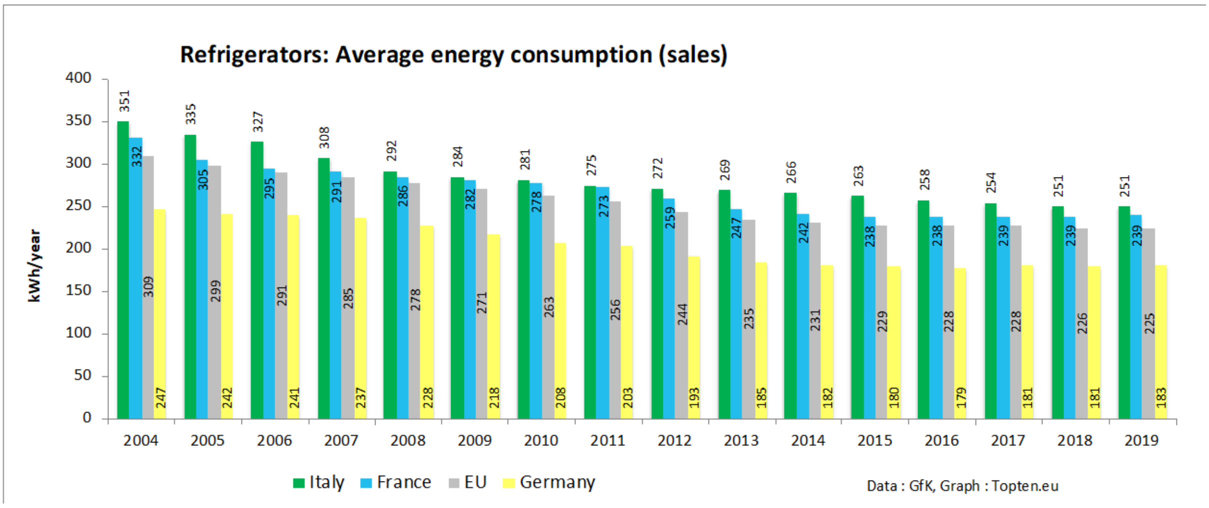


Figure 11. Refrigerators: National differences in energy classes' distribution

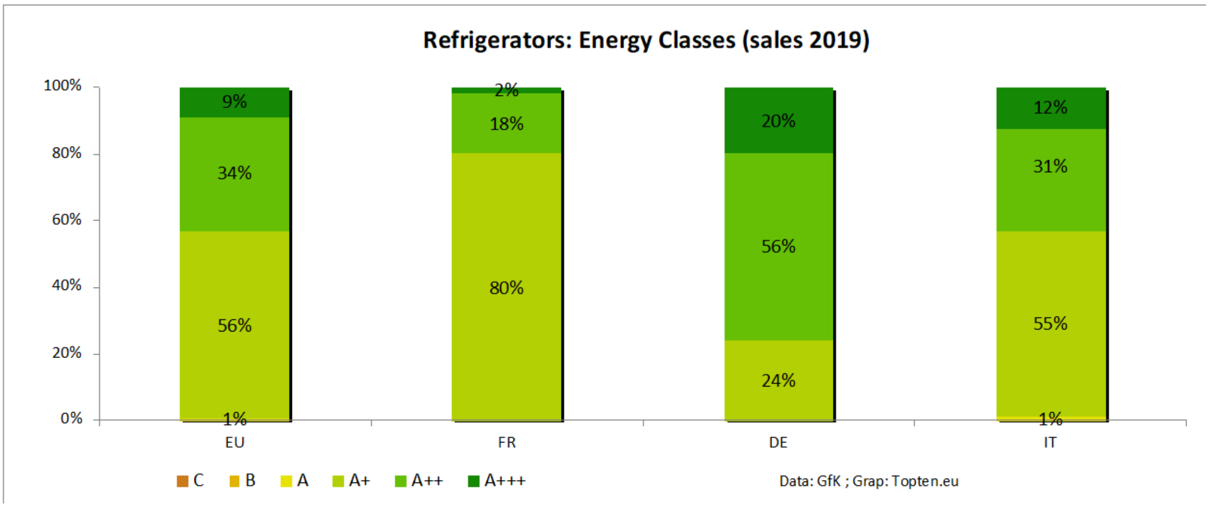


Figure 12. Refrigerators Prices illustrating marketing policies and readiness to pay

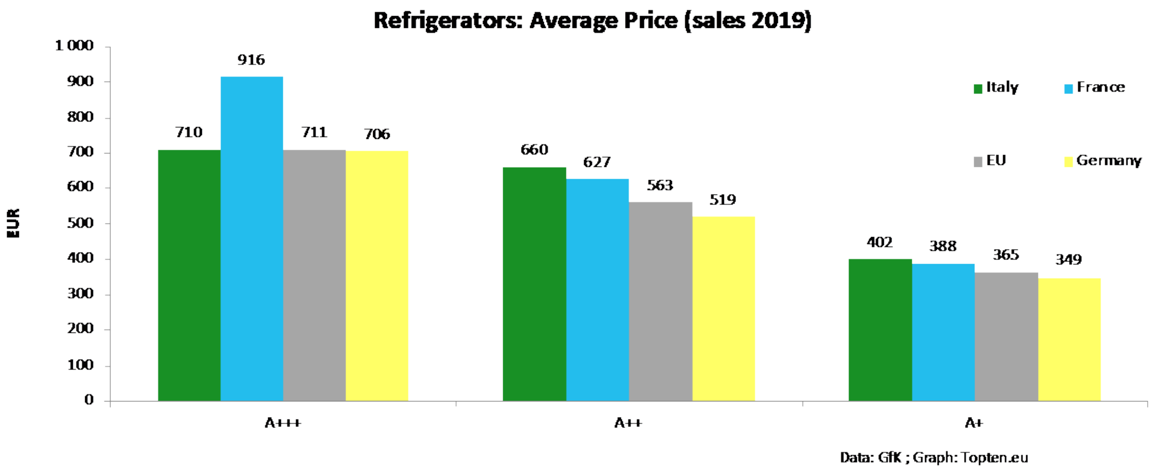


Figure 13. Washing machines: National differences in average energy consumption

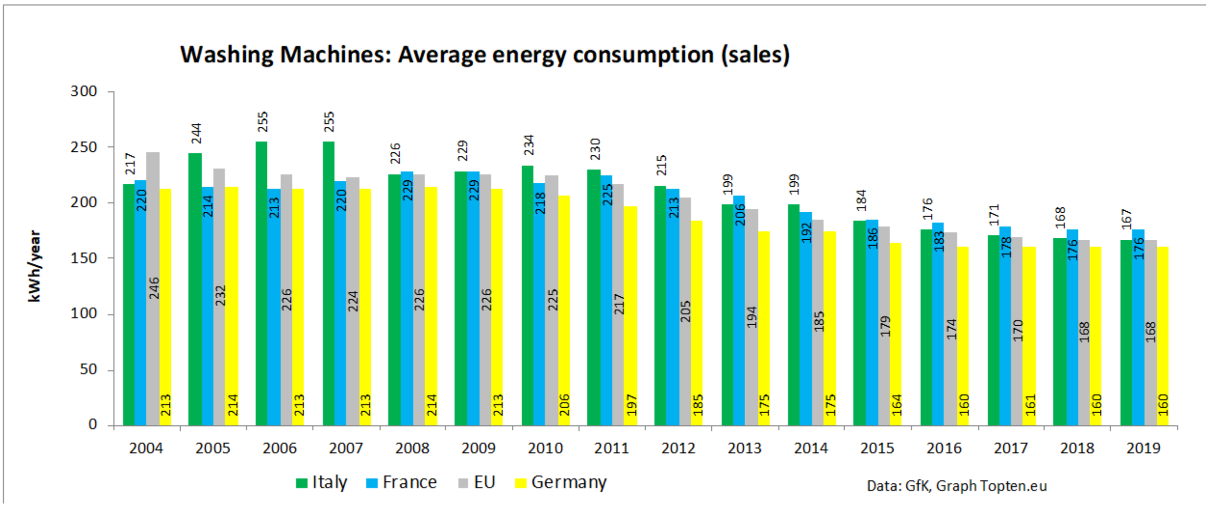


Figure 14. Washing machine prices: national differences in prices

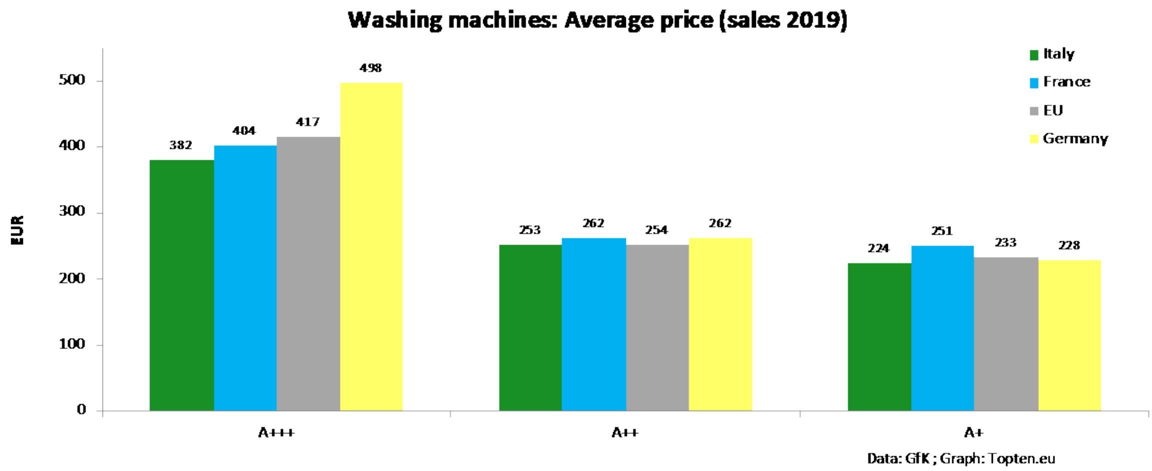
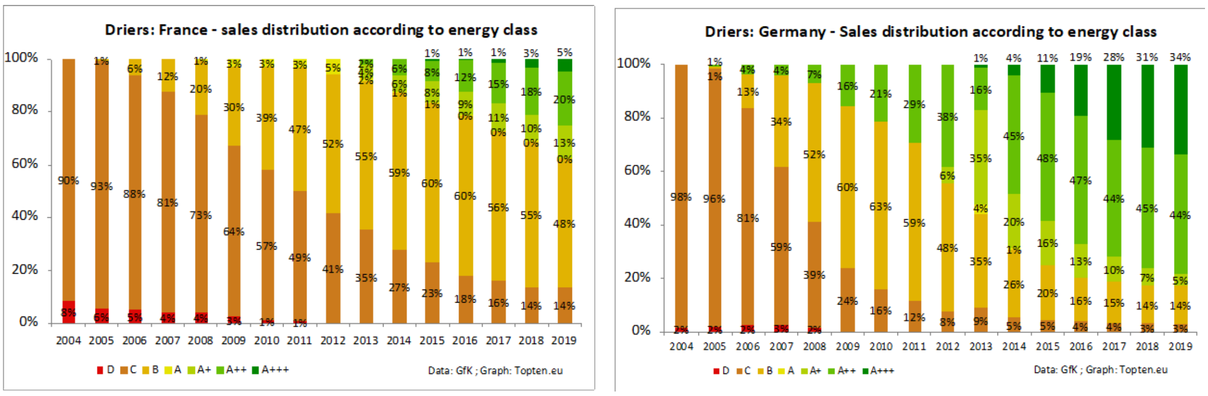


Figure 15. Tumble Driers – National differences in energy classes' distribution in France and germany



4. Advocating for combining sales data and EPREL

The study shows the enormous potential of systematic market monitoring for Europe. It reveals trends, differences between national markets and also problem areas. Regular (annual) market monitoring could allow policy makers to initiate improvements and label updates when needed, and to base their decisions on reliable data. The risks of a late revision and of setting classes on the label with a lack of ambition (as was the case for washing machines), could be minimised.

The EPREL database will provide an overview of the products on the market, allow changes in models to be identified, and is likely to facilitate international exchanges of test results, making market surveillance operations more efficient and effective. It will take time to become fully operational (and there is no mechanism in place to monitor that all products are actually registered) whereas market monitoring based on sales data could be implemented immediately.

It would be essential to complement it with sales data. EPREL information is not weighted by sales: each model will have the same weight, whether it sells well or not, it will be impossible to analyse national differences. In contrast, sales-based data is attributable to a country, takes into account models according to their weight in the market, and the aggregated data is stripped of detailed information and therefore requires less analytical work.

Information based on reported consumption values - whether from supply-side or sales-side analyses - should also be compared and contrasted with measured outcomes and user behaviour studies. Understanding these behaviours and how declared values translate into actual consumption is key: declared values and improved energy efficiency levels on the label must make sense to consumers if they are to translate into real energy savings.

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8 MONITORING

U.S. Consumer Electronics in 2020: Ownership, Usage, and Energy Consumption amid COVID-19

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Abstract

Consumer Electronics are dynamic end-uses, influenced by rapid innovation, short product cycles, and shifting user behavior. This paper summarizes a comprehensive study, sponsored by the Consumer Technology Association (CTA ®), of consumer electronics energy use in U.S. homes in 2020. Bottom-up device-level models were informed by a range of data sources, supplemented by a custom web-based survey of ownership and usage. In 2020, we estimate that 3.3 billion devices consumed 176 TWh, equal to about 12% of residential sector and 4.5% of total U.S. electricity consumption: a 23% increase relative to 2017 and apparently driven by higher usage during the COVID-19 pandemic. Newly-studied categories include robot vacuums (0.4 TWh), smart speakers (1.7 TWh), home security cameras (3.7 TWh), uninterruptible power supplies (1.2 TWh), and virtual reality headsets (0.2 TWh). Televisions (54 TWh), computers and monitors (45 TWh), and set-top boxes (18 TWh) still represent the highest share of the total consumption.

Introduction

This paper shares findings from a comprehensive study of U.S. Consumer Electronics energy use in 2020 [1] that provides an in-depth characterization of the ownership, power draw, and usage of electronics. This study, the fifth of its kind [2-5], provides energy policymakers and industry stakeholders with current information.

Consumer electronics have relatively short product cycles. New device categories can quickly gain significant market share. And existing categories can change rapidly as products advance and as user behavior shifts. To keep pace with this dynamic situation, a periodic “energy census” of consumer electronics is helpful.

The final report is public and available for download on the CTA website. Given space constraints, this paper will focus on key results, new device categories, and noteworthy trends. The final report goes into far greater detail on methods, results, and modeling decisions used for individual device categories.

Methodology

Device Category Selection

In consultation with CTA, we first selected a number of priority devices to study in the most depth. Priority was given to devices with historically high total energy consumption, higher uncertainty in preliminary estimates, and/or new devices that have gained market traction but have not yet been well characterized. Estimates for lower-priority devices were updated mainly by revising estimates of installed base figures, assuming power draw and usage characteristics were unchanged from 2017.

Energy Modeling Approach

We used a bottom-up modeling approach to evaluate consumer electronic device energy consumption, Figure [1]. For each device category studied, we first developed estimates for the typical average power draw (W) and usage (hours per year) in the relevant power modes. Multiplying power and usage by mode yields the component unit energy consumption values (UEC in kWh per year). The sum of UEC over all modes equals the total device UEC. Finally, the product of the total device UEC and the installed base (in millions of units) equals the annual electricity consumption (AEC in TWh[262]).

[262] One Terawatt-hour (TWh) equals one billion kilowatt-hours.

Figure 1. Illustrative method for calculating device-level Unit and Annual Energy Consumption.

Mode	Power Watts		Usage hours/year		Unit Energy Consumption kWh/year		Installed Base million units	Annual Energy Consumption TWh
Active	P_{active}	×	T_{active}	=	UEC_{active}			
Sleep	P_{sleep}	×	T_{sleep}	=		**$\sum = UEC_{total}$**	**× IB**	**= AEC**
Off	P_{off}	×	T_{off}	=	UEC_{off}			

To estimate the modeling inputs for ownership, power draw, and usage for each device category, we drew upon field-monitoring studies, power databases and targeted device measurements, CTA market research, and industry input.

Installed Base

The installed base represents the total number of devices in U.S. homes that were plugged in recently. This definition excludes devices that were *owned* but not *plugged in,* so values may differ from ownership figures published elsewhere. Installed base estimates came from market research studies, most commonly the ownership and sales reports published by CTA Market Research [6-7], the Consumer Electronics Usage Survey (see next subsection), and, to a lesser extent, ownership and sales data from other sources. For most devices, the installed base estimates have the lowest uncertainty of any AEC component.

Power Draw by Mode

All consumer electronics have at least two basic operating modes – *on* and *off* – and most have other modes such as *idle, standby*, *sleep*, *hibernate,* or *charging*. Within a specific power mode, device power draw can vary appreciably due to changes in operation such as variable processor utilization, display brightness, or audio signal. For each device category, we identified the most relevant power modes and developed estimates for the average power draw of its installed base in each mode, attempting to reflect real-world usage scenarios as well as possible.

We relied on several other sources to estimate power draw by mode, including: energy consumption characterization studies, field measurement campaigns, product power draw and energy consumption databases (ENERGY STAR [6], California Energy Commission [7], Energy Efficiency Voluntary Agreements [8]), measurements performed by CTA member companies, and targeted measurements performed by Fraunhofer USA.

Usage by Mode

For most device categories, the average annual time spent in different power modes is the most challenging to estimate accurately. While long-term field studies of demographically-representative populations would provide the best data, these are challenging to implement and expensive to administer. Instead, we relied on the Consumer Electronics (CE) Usage Survey, data from prior field measurement campaigns, and data from prior energy consumption characterization studies.

The CE Usage Survey responses served as inputs into more refined models used to assess computer, monitor, television, and video game console usage. We posed more questions for computers and video game consoles because they have substantial AEC values that depend strongly on usage behaviors and power management settings.

Consumer Electronics Usage Survey

To develop refined estimates of the installed base, device characteristics, and user behavior, we worked with CTA Market Research to organize an online survey of demographically representative households, hereafter the CE Usage Survey. This survey addressed certain priority devices including televisions, computers, monitors, video game consoles and some newer devices, including smart speakers, security cameras, robot vacuums, and virtual reality headsets.

Usage questions were designed to elicit how many hours a device spends in different power modes. For simple devices, we asked direct questions about usage frequency and duration. For more complex devices, like computers and monitors, additional questions were asked to identify likely power management settings. Inferences from the survey were then used to model the typical device behavior.

For some devices, like televisions, we asked detailed questions about the device itself, such as approximate screen size and display type. This is important because usage can be correlated with features that influence energy consumption.

Specific questions were added to determine the possible impacts of the COVID-19 pandemic on device usage for televisions and computers.

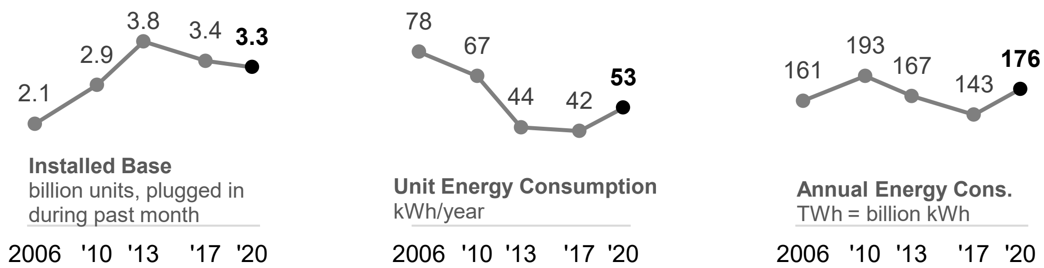
Multiple survey fields were used to model the energy consumption of particular devices in households. Demographic weightings were then applied to estimate the average unit energy consumption of each device type across the population. More details, including the survey questions and device-specific modeling methods, are given in the final report [1].

Energy Consumption Results

Overall Energy Trends

We estimate that 3.3 billion consumer electronics devices consumed about 176 TWh in 2020, equal to about 12% of residential sector and 4.5% of total U.S. electricity consumption. Powering these devices costs about $23 billion annually. For the average household, this is about 1,465 kWh or $190 per year.

Figure 2. Recent trends in consumer electronics energy consumption.



While total consumer electronics energy use had been trending downward, the 2020 energy total exceeded that of 2017 by 23%. Results of the CE Usage Survey suggest that significantly higher usage, very likely related to the COVID-19 pandemic, drove a large portion of this increase. Active and idle modes accounted for the vast majority (85%) of the energy consumed by the devices studied in depth.

Device-Level Consumption

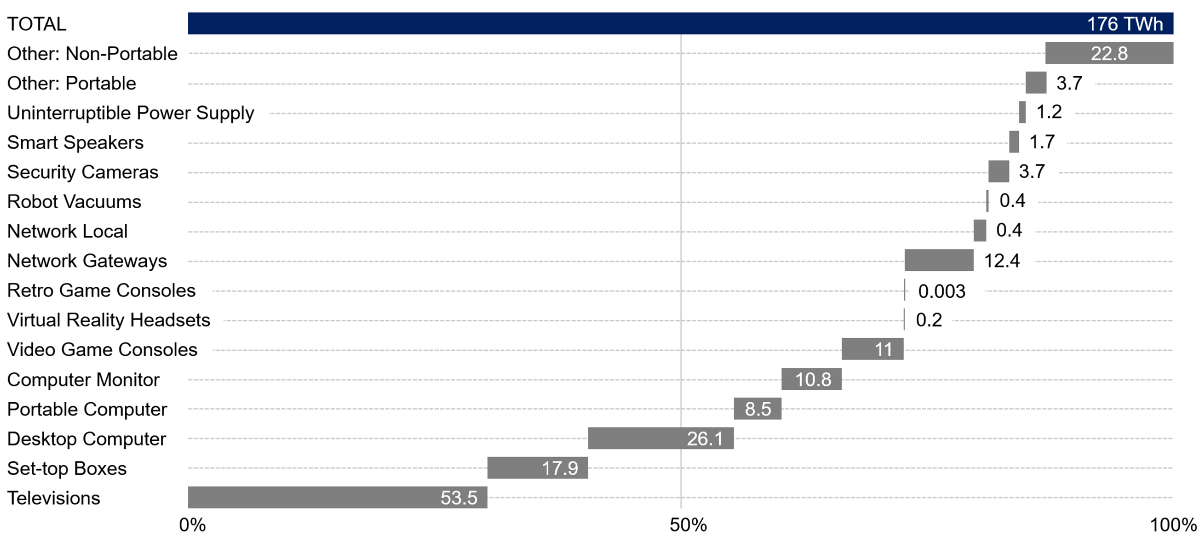
The estimated energy use breakdown by device category is shown in Table 1 and Figure 3. Three categories account for just over half the total energy consumption: televisions (30%), desktop computers (15%), and set-top boxes (10%). The *other devices* studied in less detail account for about 35% of the total number of units but only about 15% of the total energy consumption. The devices studied in depth, therefore, account for the bulk of the total consumption.

Table 1. Energy use estimates for consumer electronics in U.S. homes in 2020.

Device	Units (mill.)	*Power (W)* Active	Idle	Sleep	Off	*Usage (hours/year)* Active	Idle	Sleep	Off	UEC (kWh/yr)	AEC (TWh)
Computer, Desktops	79	73	49	2.5	1.1	2,310	3,190	1,500	1,760	331	26.1
Computer, Portables	123	19	9.1	0.7	0.3	2,145	2,805	1,950	1,860	69	8.5
Computer Monitors	123	25	-	0.6	0.4	3,385	-	3,450	1,925	86	10.8
Network Gateways	105	13.5	-	-	1.3	8,760	-	-	-	118	12.4
Network Local Equip.	38	6.5	-	-	1.0	8,760	-	-	-	57	2.2
Robot Vacuums	14	27	0.2	-	3.0	80	66	-	8,614	28	0.4
Security Cameras	117	3.6	-	-	-	8,760	-	-	-	31	3.7
Set-top Boxes, Subscription	171	11	-	9.5	-	5,110	-	3,650	-	89	15.2
Set-top Boxes, Digital Stream	93	2.8	-	1.7	-	1,925	-	6,835	-	17	1.6
Set-top Boxes, Standalone	2	33	-	30	-	4,200	-	4,560	-	275	0.6
Set-top Boxes, Over-the-Air	16	6.5	-	0.8	-	3,940	-	4,820	-	29	0.5
Smart Speakers	76	3.0	2.5	-	-	732	8,028	-	-	22	1.7
Televisions	285	81	-	-	2.3	2,120	-	-	6,640	188	53.5
Uninterruptible Power Supplies	5	26	-	-	-	8,760	-	-	-	224	1.2
Video Game, Major Consoles	109	67	47	-	3.4	905	350	-	7,505	103	11.2
Video Game, VR Headset	11	12	-	-	1.8	560	-	-	8,200	22	0.2
Video Game, Retro Game	4		-	-	0.0	240	-	-	8,520	0.7	0.0
Video Game, Portable	49	-	-	-	-	-	-	-	-	4.3	0.2
Other Devices, Portable	1,058	-	-	-	-	-	-	-	-	3.5	3.7
Other Devices, Non-Portable	904	-	-	-	-	-	-	-	-	25	22.8
TOTAL	**3,334**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**53**	**176**

Notes: Top three energy-consuming devices highlighted.
Power modes in this table are approximate. See final report for more detail [1].

Figure 3. Energy use estimates by device type in U.S. homes in 2020.



COVID-19 led to higher energy usage for major devices

While it is not always possible to directly attribute top-level changes in energy consumption to a single factor, 2020 was clearly a special case. During the COVID-19 pandemic, people spent far more time at home. This behavior was directly linked to the increased usage estimates for 2020. Whether these usage trends will continue to increase, remain stable, or revert to prior levels is yet to be seen.

To assess these potential impacts, we included COVID-19 specific survey questions for televisions and computers, asking respondents to estimate by how much their daily usage has increased or decreased per day. The results agree with and explain most of the increased usage.

For instance, the average daily television active mode usage (the total number of hours a TV is on) increased by nearly 50% from 2017 to 2020, going from 3.9 to 5.8 hours per day per TV. This increase is in line with the self-reported COVID-19 impact of +1.5 hours per day per TV.

Similarly, the active use of computers was also higher than usual. Our surveys found the average desktop and laptop were used for 5.7 and 5.5 hours, respectively, about 30% higher than in 2017. Responders indicated an average increase of +1.5 hours per day per computer due to the pandemic.

Video game consoles usage was about 20% higher than in 2017. Although a COVID-19 specific question was not asked for this category, it is most likely related.

For these device categories, active mode power draw is substantially higher than standby or off-mode, so the effects translate directly into higher UEC and AEC values. The same is true of computer monitors, which are directly influenced by computer usage.

Altogether, the increased time spent at home and the resulting increase in usage explains much of the total energy increase observed across categories.

A Closer Look at Major Device Categories

This section looks at the findings for several major device categories that were studied in depth since 2013. Table 2 shows recent trends for Installed Base, Unit Energy Consumption, and Annual Energy Consumption.

Table 2. Trends in U.S. ownership and energy consumption for selected devices.

	Installed Base millions			*Avg. Unit Energy Consumption kWh/yr*			*Annual Energy Consumption TWh*		
Device \ Year	2013	’17	’20	2013	’17	’20	2013	’17	’20
Televisions	301	284	285	166	123	188	50	35	53.5
Set-top Boxes, Subscription[1]	239	228	171	123	107	89	29	25	15.2
Video Game, Major Consoles	128	105	109	88	79	103	11	8.3	11.2
Computer, Desktops	88	72	79	186	246	331	16	18	26.1
Computer, Portables	93	122	123	51	42	69	4.7	5.1	8.5
Monitors	97	101	123	58	80	86	5.7	8.1	10.8
Network Gateways	113	93	105	58	107	118	6.6	9.5	12.4
Network Local Equip.	94	39	38	59	52	57	5.5	2.0	2.2

[1] Includes DVR, Non-DVR, Thin client, and Cable DTAs. STB values in the ’17 column are actually for 2016.
Based on [1-3].

Television energy consumption up about 50% amid higher usage

Televisions remain the most owned and highest-consuming category. The 2020 installed base remained relatively flat at around 285 million units vs. 284 million units in 2017. In that time, UEC and AEC increased by about 53% to 188 kWh/yr and 54 TWh, respectively.

This energy increase reversed a major downward trend that started around 2010, when TV energy consumption peaked around 65 TWh. From 2010 until 2020, Cathode Ray Tube (CRT) displays were steadily being removed from the installed base, while modern LCD and LED TVs took their place. As of 2020 we estimate the transition away from CRTs is nearly complete. Only 6% of TVs were identified as CRTs in the 2020 CE Usage Survey.

Relative to 2017, on-mode power estimates increased slightly from 77 to 81 W. This increase was partly because of a power-adjustment factor that was used to account for differences in as-tested vs. real-world screen brightness. User preferences and brightness settings can influence TV power draw appreciably, yet the prevalence of different brightness settings is not well characterized.

Off-mode power estimates also increased from about 1.0 to 2.3 W, due to considerations about networked and active standby modes of smart-enabled TVs, particularly those that allow for instant-on or screen-casting capabilities. Some models can use 10 W or more in these active standby modes, while others use much less. The prevalence and of these active modes is also not yet fully understood.

As discussed earlier, TVs experienced a 50% increase in on-mode usage, going from 1,410 to 2,120 hours per year, primarily driven by the COVID-19 pandemic and additional time spent at home. This was the main driver behind the category's energy increase. It remains to be seen if this increased usage trend will continue or if usage will eventually regress to pre-pandemic levels.

Computers and Monitors

Computers and their monitors consumed an estimated 45 TWh in 2020, with computers accounting for 80% of the total. This represents an increase of nearly 50% since 2017, driven almost entirely by higher active usage during the pandemic. Secondary effects included decreases in on-mode power and slight-to-moderate increases in the installed base of desktops and external monitors.

Desktop and portable computers[263] and their external monitors all consumed more energy in 2020, primarily because of higher active mode usage. Users reported an average active usage of about 5.5-6.2 hours per day per computer. This was reportedly 32-51% higher than pre-pandemic levels.

More than most categories, computer and monitor usage depends also on device power management settings and behaviors. To evaluate these factors, we included targeted survey questions, Table 3, that fed into energy models. These models account for transitions between power modes during typical daily usage to estimate the total time spent in each mode.

Table 3. Usage survey responses for computers and monitors [1].

	Desktop		
Survey Question	Tower	All-in-One	*Portable*
Active Usage Yesterday? (h/day)	5.7	6.2	5.5
Before 5PM	3.4	3.7	3.1
After 5PM	2.4	2.5	2.4
Owner-Reported Change in Usage Due to Pandemic (h/day)	+1.4	+2.1	+1.6
Percent Change	+32%	+51%	+41%
First Use State?			
PC On & Display On	19%	24%	14%
PC On & Display Off	29%	33%	20%
PC Sleep	18%	18%	34%
PC Off / Hibernate	34%	25%	32%
Power Management Status?			
No Power Management	23%	29%	19%

263 Including laptops and Chromebooks, but excluding tablets and smartphones.

Survey Question	*Desktop* Tower	All-in-One	*Portable*
Display Sleep Only	37%	38%	32%
PC Sleep (implies display sleep)	25%	21%	29%
PC Off / Hibernate	15%	13%	20%

Notes: Active usage values are as-reported by owners and differ from those used in the energy models. Modeled active usage depends on other factors like power management settings and behaviors.

Monitor energy use increased by about 20% from 2017 reaching 10.8 TWh. Three factors drove this change. First, the installed base increased by about 22% to 123 million units. Second, active usage increased by about 38% to about 9.2 hours per day. And third, the average active mode power draw declined by nearly 20% to 25 W. Sleep- and off mode power declined slightly, at 0.6 and 0.4 W, respectively. As with televisions, CRT monitors are mostly gone. We estimate that LCD monitors make up about 93% of the installed base according to the survey, driving the decline in active mode power draw.

Video Game Consoles

Major video game consoles consumed an estimated 11 TWh or 103 kWh per year per unit, in 2020. Since 2017, we estimate that major console consumption increased by about 20%, almost entirely due to higher active usage. Active usage was reportedly higher than 2017 by up to 60% at around 2.5 hours per day.

This is likely related to increased usage of consoles for streaming video playback and more time spent at home during the pandemic. The total installed base and average power draw by mode were relatively unchanged from 2017 estimates.

Other video games, including Virtual Reality (VR) headsets, portable games, and retro game devices consumed far less at around about 0.4 TWh. We estimate that about 11 million VR headsets consumed about 0.2 TWh or 22 kWh per year per unit in 2020.

Retro game consoles are reissued standalone clones of discontinued legacy consoles, like the NES Classic, Sony PlayStation Classic, or SEGA Genesis Mini. These generally use relatively little power, about 3 W in active mode. While CTA estimates indicate ownership of about 45 million units, our Consumer Electronics Usage survey found that only a small fraction (10%) were plugged in recently. Consequently, we estimate their energy use to be exceedingly small at around 1 kWh per year and well below 0.01 TWh.

Set-Top Boxes and Small Network Equipment

A major portion of Set-Top Box and Small Network Equipment industry stakeholders have signed onto voluntary agreements to improve the energy efficiency of these devices. As part of these voluntary agreements, the industry provides data that characterizes the energy consumption of devices procured. This information is then published in annual reports, which we use to study these devices.

Subscription Set-top box energy use estimates have declined by almost half from 2013 to 2020, when they used about 15 TWh. This decrease occurred mainly for two reasons. First, the installed base shrunk by about 13%, with non-DVR boxes disappearing at the fastest rate. And second, the average unit energy consumption has also declined because newer boxes use less power. The average DVR set-top box shipped in 2016 uses about 24 W in active mode, compared with 17 W for those shipped in 2020.

Small network equipment energy use estimates have increased in recent years, with a total of 14.5 TWh in 2020. Gateway devices, including Integrated Access Devices (IADs) and broadband modems, used on average 13.5 W or 118 kWh/year per unit in 2020, about 16% more than in 2017.

Newly-Studied Device Categories

Several device categories were studied in depth for the first time. This section reviews the key findings.

Smart Speakers

Smart speakers or virtual assistant speakers have grown rapidly in recent years. Devices like the Amazon Echo, Google Nest Hub, and Apple HomePod can recognize and respond to voice commands, stream audio, and control other smart home devices. Smart speakers maintain a wireless network connection while waiting for commands and may include a built-in display. We estimate smart speakers consumed about 1.7 TWh per year or 22 kWh/yr per unit in 2020.

The CE Usage Survey found a 36% household penetration, with 1.8 units per owner household, implying 76 million units installed in 2020. The typical power draw of smart speakers is relatively low: 2.5 W in standby and 3.0 W in active mode. Most of the energy consumption occurs in network standby mode while listening for commands. Users reported an average of about 107 minutes playing music and 4.4 voice commands per day, or about two hours of active time per day.

Security Cameras

Home security cameras include dedicated indoor/outdoor cameras for home video monitoring, typically USB or battery-powered. We also considered smart video doorbells and baby monitors. We estimate these devices used 3.7 TWh or 31 kWh per unit in 2020.

The CE Usage Survey found a 24% household penetration of security cameras, with 2.9 units per owner household, implying 85 million units. Baby monitors had a 15% penetration, 1.2 units per home, implying 22 million units. And smart doorbells, had a 7% penetration, 1.2 units per owner household, implying 11 million units. Altogether, this is about 117 million units.

For indoor/outdoor security cameras, we estimated typical continuous power draw in the 3-5 W range, based on common models, or about 37 kWh per unit. Baby monitors were treated similarly, except that some were assumed to be audio-only with an average of 24 kWh per unit. Smart doorbells, in contrast, are typically battery powered and can go months between charges, and consume less than 1 kWh/yr on average.

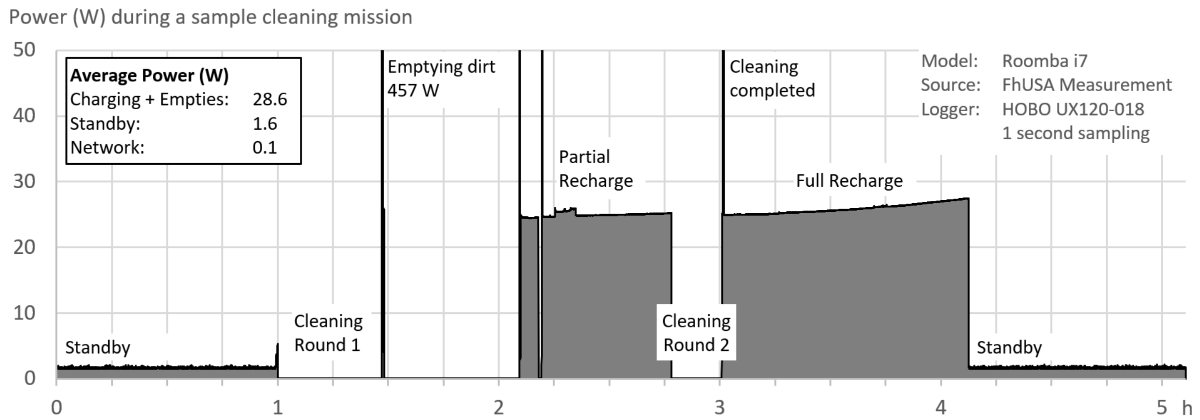
Robot Vacuums

Robot vacuums perform autonomous floor cleaning tasks in the home. In between cleaning missions, and sometimes during missions, the robot returns to a powered base station to recharge its batteries and/or empty its dirt payload. The vacuum system connects to a wireless home network to send and receive commands.

We estimate there were about 14 million robot vacuums in service in 2020 based on cumulative sales figures from 2016-2020 [7]. We estimate robot vacuums consume about 0.4 TWh or 28 kWh/yr per unit in 2020.

Based on aggregated user data from the U.S. market leader, we estimate the average unit performs 141 missions per year. Each mission is associated with 28 minutes of charging and 34 minutes cleaning. The vast majority of robot vacuum energy consumption occurs in standby mode, when the robot is docked with the charging station awaiting commands. Thus, the unit energy consumption is not so dependent on the frequency or duration of usage. An example measured power profile for a cleaning mission is shown in Figure [4].

Figure 4. Measured power draw for a sample robot vacuum cleaning mission.



Uninterruptible Power Supplies

Uninterruptible Power Supplies (UPS) can provide temporary battery backup power, surge protection, and power conditioning for critical electronic devices. During normal operation, the connected devices are powered from the electric grid and the battery remains charged. When grid power is interrupted, control circuitry rapidly detects the outage and automatically diverts to battery power. The rapid switch provides continuous operation until the batteries are depleted, typically minutes or hours depending on the load and UPS capacity.

We estimate 5 million UPS devices in homes consume up to 1.2 TWh or 224 kWh/yr per unit in 2020. This is likely an upper-bound estimate, as it was based in part on data from commercial use cases, where duty cycling and loads may be higher than in residential applications.

The analysis was based largely on data from a U.S. Department of Energy rulemaking from 2016 that found about 10% of UPS shipments were to the residential sector, implying 5 million units in 2020. Three kinds of UPS were considered: Voltage and Frequency Dependent (75 kWh/yr), Voltage Independent (124 kWh/yr), and Voltage and Frequency Independent (804 kWh/yr), and their energy use estimates were based on efficiency metrics provided by ENERGY STAR standards and the portion of qualified units sold by year.

Conclusions

This paper summarizes results from a comprehensive study that evaluated the ownership, power draw, usage, and energy consumption characteristics of U.S. consumer electronics in 2020. The following conclusions were identified:

1. U.S. Consumer Electronics used about 176 TWh (approximately $23 billion) in 2020. This is about 4.5% of the total U.S. electricity consumption and 12% of the residential sector electricity consumption. Per-household consumption was about 1,465 kWh per year ($193).

2. Total consumer electronics energy consumption increased by about 24% relative to 2017. This was primarily driven by a 50% increase in active usage in major categories like televisions and computers, as people spent more time at home during the COVID-19 pandemic.

3. Newly studied device categories include robot vacuums (28 kWh/yr and 0.4 TWh), smart speakers (22 kWh/yr and 1.7 TWh), home security cameras (31 kWh/yr and 3.7 TWh), uninterruptible power supplies (224 kWh/yr and 1.2 TWh), and virtual reality headsets (22 kWh/yr and 0.2 TWh). Together, these represent 4% of the consumer electronics energy total.

4. The highest-consuming devices include televisions (188 kWh/yr and 53.5 TWh), desktop computers (331 kWh/yr and 26.1 TWh), and subscription set-top boxes (89 kWh/yr and 15.2 TWh). Together, these three categories represent more than half of the consumer electronics energy total.

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Examining the Turkish Residential Refrigeration Electricity Use by Stock Modelling and Decomposition Analysis, 2010-2020

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Abstract

Energy efficiency is one of the main pillars of achieving net-zero climate targets. Thus, data-driven policies and programs are needed to reveal untapped energy efficiency potential. The available data on the household appliances stock are very limited for Turkey. The existing studies are mostly based on survey studies applied to a limited number of households, which cannot be accepted as a dependable representation for the Turkish residential sector. Refrigerators are the appliances with the highest energy consumption in most houses. Thus, determining the refrigerators' stock and consumption plays a vital role in residential end-use energy studies. In the first step of the study, the refrigerator stock between 2010 and 2020 is determined using the annual sales data, appliance service life, and the number of households. The service life of refrigerators is estimated using a modified Weibull distribution function. The historical refrigerator stock is then used to identify annual stock consumption using the energy label data of the refrigerators sold each year. Electricity consumption of refrigerator stock is estimated to decrease from 10,904 GWh in 2010 to 9,366 in 2020. In the second step of the study, the energy savings due to efficiency improvement in the refrigerators are estimated between 2010 and 2020 based on the LDMI decomposition method. The results revealed that the energy consumption of the total refrigerator stock would be 44% higher if there were no improvements in energy efficiency.

Introduction

Turkey submitted its emission reduction target by 21% until 2030 based on the business-as-usual scenario to the United Nations Secretariat at COP21 as its Intended Nationally Determined Contribution. Six years later, the Paris Agreement was accepted on October 7, 2021, by voting in the Grand National Assembly of Turkey. After, Turkey announced its goal of being net-zero in 2053, which coincides with the 130th anniversary of the Republic.

There is undoubtedly a need for Turkey for a transformation in all processes from production to final consumption to reach the net-zero target. The residential energy consumption, which has a 22.6% share in Turkey's final energy consumption in 2020, has grown by 35.7% in the last five years. Considering that the energy demand will increase in the coming years with the increasing population and welfare, one of the most challenging sectors in the net-zero transformation is expected to be the residential sector.

The final energy consumption of the Turkish residential sector was 25.7 million toe in 2020, and natural gas has the largest share with 50.1%. It is followed by electricity with 20%, coal with 16.5%, bioenergy and waste with 6.2%, geothermal with 3.3%, and solar with 2.1% [1]. While all energy sources except electricity are used for space heating, domestic hot water, and cooking, electricity is consumed for household appliances, lighting, and cooling purposes. However, there are no officially published statistics on the distribution of energy consumption on Turkey's end-use basis. According to Eurostat data, 63.6% of the energy consumed in residential buildings in the EU is used for space heating, 14.8% for hot water production, 14.1% for lighting and household appliances, 6.1% for cooking, 0.4% for space cooling, and 1% for other uses [2].

Turkey has put into practice many policies and strategies for the efficient use of energy resources and utilization of energy-saving potential in all sectors. The framework for energy efficiency programs was announced with the Energy Efficiency Law published in 2007. Then, its secondary legislation, the Building Energy Performance Regulation and the Regulation on Increasing Efficiency in the Use of Energy Resources and Energy, were published in 2010 and 2011, respectively. The Framework Eco-design Directive (EU) 2009/125/EC and The Framework Labeling Directive (EU) 2010/30/EU were harmonized in 2010 as the Regulation on Environmentally Sensitive Design of Energy-Related Products and the Regulation on Displaying Energy and Other Resource Consumption of Products through Labeling and Standard Product Information [3, 4]. Several communiqués have been published under these regulations for electrical household appliances and device groups. The labeling and eco-design communiqués for refrigerating appliances were revised in 2021 and published as the Communiqué on Energy Labeling of Cooling Devices (2019/2016/EU) (SGM:2021/8) and the Communiqué on Environmentally Responsible Design Requirements for Refrigeration Devices (2019/2019/EU) (SGM: 2021/7) by the Ministry of Industry and Technology [5, 6].

With the National Energy Efficiency Action Plan 2017-2023, 12 actions were determined to increase energy efficiency in buildings. One of the building sector actions is named "Rehabilitate existing buildings and improve energy efficiency." This action aims to carry out awareness-raising activities and bring direct or indirect support for increasing energy efficiency in equipment such as thermal insulation, efficient windows, lighting, white goods, heat pumps, boilers, and elevator motors [7]. Thus, Turkey announced a tax reduction program with Presidential Decree No. 287, which decreased the special consumption tax (SCT) rate by 6.7% for white goods included in the list (IV) of the SCT Law. The program took place between October 31, 2018, and December 31, 2018, and was extended until June 30, 2019 [8, 9].

The available data for household appliance stock for Turkey is limited to ownership rates only. The literature lacks information on both the Turkey's residential refrigerator stock and its energy consumption. However, annual sales of white goods are published by the Turkish White Goods Manufacturers Association (TURKBESD). According to TURKBESD, refrigerator sales were 2.17 million units in 2017. Despite the tax reduction program, the sales decreased to 1.81 million in 2018 and 1.72 million in 2019. But recovery was observed in 2020, and sales increased to 2.02 million [10]. On the other side, Selçuk (2018) calculated household electrical home appliance ownership rates by using the "Household Budget Survey" data conducted by the Turkish Statistical Institute (TUIK) in 2003 and 2016. Her study showed that 98% of the households had at least one refrigerator in 2016 [11]. In another survey conducted by the Ministry of Energy and Natural Resources (MENR) based on 3000 people, the responses revealed that 97% of the households had a refrigerator in 2020 [12]. The appliance ownership rates differ in emerging and developed countries. Although the household ownership rates reached 100% in the USA, UK, France, and Japan and 99% in Germany, they remained below 90% in emerging economies such as China, India, and South Africa [13].

According to the European Energy Agency, the average consumption of refrigerators decreased by 38% in the period 1990-2016 [14]. Likewise, the International Energy Agency indicated that 22% of savings are achieved on average globally, and the longest-running regulation achieves 63.8% saving due to the eco-design and labeling regulations on refrigerators [15].

Zachariadis, Samaras, and Zierock [16] developed the dynamic modelling approach by employing the Weibull Probability Density Function in order to determine the total stock amount. Diawou et al. [17, 18] adapted Zachariadis, Samaras, and Zierock's [16] study to identify the stock amount of household appliances. Thus, in countries such as Turkey that do not have stock data for household appliances, the total stock can be estimated by using annual sales data and survival curves using the dynamic modelling approach instead of making expensive energy audits and field surveys. If the total stock is known, the stock energy consumption can be calculated according to the eco-design and labeling regulations.

On the other hand, it is important to measure the effectiveness of existing policies and to reveal the progress in energy efficiency in order to find out the right policy options for energy consuming equipment. In the literature, different decomposition analysis methods have been proposed for policy analysis and examining the factors that cause changes in energy consumption. However, the literature lacks of comprehensive studies on examination of appliances energy use with a holistic approach.

In this study, the total refrigerator stock and its energy consumption are estimated using the stock modeling to see the electricity consumption trend of refrigerator stock over the years. Afterward, the savings achieved through energy efficiency improvements between 2010 and 2020 are determined using the index decomposition analysis approach. In this context, the available data and the employed methodology are presented in Section 2. The results are shown in Section 3, and the conclusions are presented in Section 4.

Data and Methodology

The most accurate method for determining household appliances' stock and their energy consumption is to conduct detailed surveys and audits. These surveys and audits should cover sufficient samples to represent all socioeconomic levels, and also long-term monitoring is done to observe seasonal factors. However, the surveys and audits are too costly and time-consuming, considering their sample size. The household appliance ownership rates can provide a rough estimate on the stock of household appliances in-use. The total appliance stock can be calculated by multiplying the total number of households with the appliance ownership rate as given in Equation (1). For example, there are 24.6 million households in 2020 according to the Turkish

Statistical Institute, and the refrigerator ownership rate is 97% which is obtained by the MENR [12] survey. Thus, the total refrigerator stock can be determined as 23.86 million units.

$$Stock_i = HH_i \times \gamma_i \tag{1}$$

i : Analyzed year

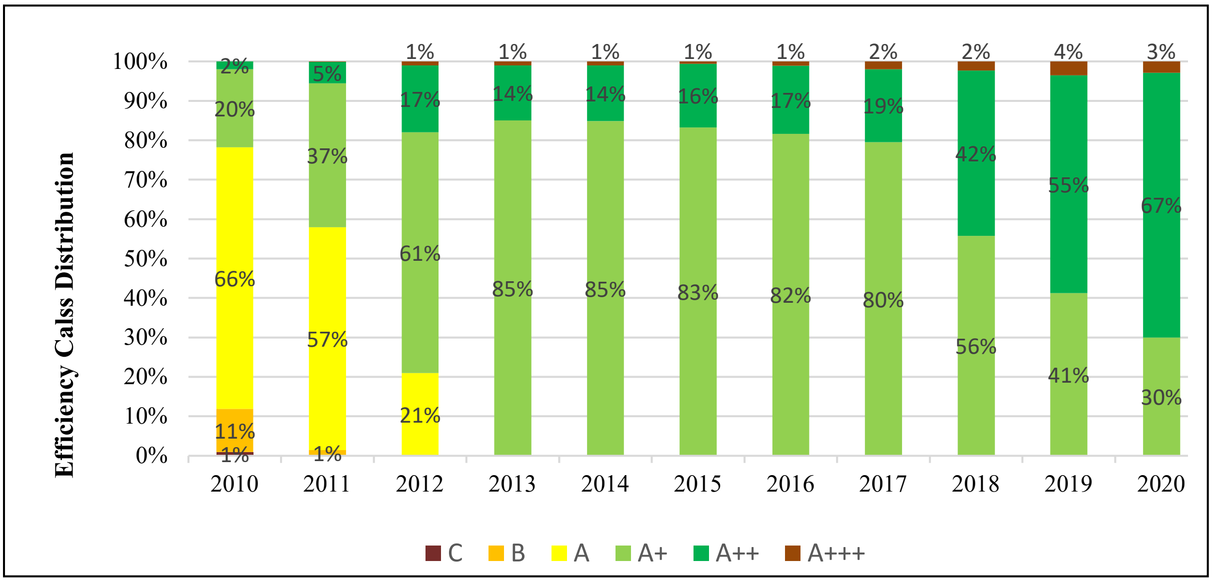
$Stock_i$: Total appliance stock in use in year i

HH_i : Total number of households in year i

γ_i : Appliance ownership rate in year i

The total refrigerator stock can be calculated accurately if retired product stock is also known. Information on retired stock does not exist for Turkey, but the sales figures are announced yearly by TURKBESD. Breakdown of refrigerator sales according to energy label classes is presented in Figure 1. A sharp decline was observed in the sales of refrigerators with A and below energy labels after 2011, since the refrigerators must have a minimum A+ energy class as of July 1, 2012. However, the sales of refrigerators with the A+++ energy class remained at a certain level due to their high purchasing cost.

Figure 1. Efficiency classes of refrigerator sales (Adapted from TURKBESD [10])



According to Diawuo et al. [17], the products that retire each year can be determined by using Equation (2):

$$AR_i = S_i \times \big(1 - \varphi(0)\big) + \sum_{j=i-k}^{i-1} S_j \times \big(\varphi(i-j+1) - \varphi(i-j)\big) \tag{2}$$

AR_i : Retired appliance stock in year i

S_j : Sales in year j

k : Age of appliance in terms of years

$\varphi(i-j+1), \varphi(i-j)$: Survival probability with age $(i-j+1)$ and $(i-j)$, respectively

Diawou et al. [17, 18] used the survival curve suggested by Zachariadis, Samaras, and Zierock [16] to calculate the number of retiring household appliances in their study. The "Adapted Weibull Probability Density Function" for the survival probability proposed by Zachariadis, Samaras, and Zierock [16] for household appliances is presented in Equation (3).

$$\varphi(k) = exp - \left[\left(\frac{k+b}{T}\right)^{b}\right];\ \varphi(0)\ \cong 1 \tag{3}$$

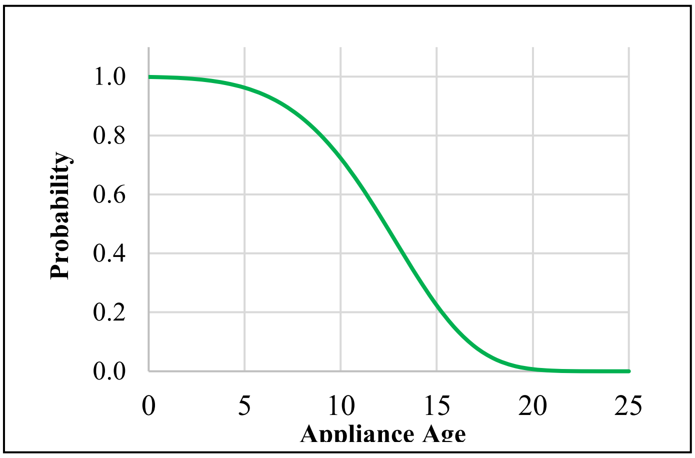
$\varphi(k)$: Survival probability being k year old

b : Failure steepness (>1)

T : Characteristic service life (appliance lifespan)

Based on the MENR [12] study, the lifespan T is assumed as 22 years. Zachariadis, Samaras, and Zierock [16] indicated that b value converges to 50% of the average lifespan in their studies. This information presents the survival curve created for refrigerators in Figure 2.

Figure 2. Survival curve for refrigerators



The Energy Efficiency Index (EEI) and Standard Annual Energy Consumption (SAEC) of the household refrigerators are given by Equation (4) and Equation (5) in the Communiqué (SGM 2011/17) on Environmentally Responsible Design Requirements for Household Cooling Appliances [19].

$$EEI = \left(\frac{AE_R}{SAE_R}\right) \times 100 \tag{4}$$

$$SAE_R = VE_{eq} \times M + N + CH \tag{5}$$

AE_R : Annual energy consumption of refrigerator (kWh/yr)

SAE_R : Standard annual energy consumption of refrigerator (kWh/yr)

VE_{eq} : Equivalent volume of the refrigerator (liters)

CH : Equal to 50 kWh/yr for refrigerators with a chill compartment having at least 15 liters storage volume;

M and N: Coefficients defined in the Communique.

The main factors behind the increase in energy consumption and the effectiveness of the energy efficiency policies and programs can be understood using the Logarithmic Average Divisia Index (LDMI) decomposition analysis. The additive type LDMI is used to examine the factors that cause changes in energy consumption of the refrigerator stock in this study. Accordingly, the change in energy consumption can be expressed in terms of activity, structural and energy intensity effects as presented in Equations (6) and (7).

$$E = \sum_{l} E_l = \sum_{l} Q \frac{Q_l}{Q} \frac{E_l}{Q_l} = \sum_{l} Q S_l I_l \tag{6}$$

E and E_l: Energy consumption of the sector and subsector, respectively

Q and Q_l : Activity level of the sector and subsector, respectively

S_l : Structural effect of subsector l

I_l : Energy intensity of subsector l

Between year t and reference year 0, the change in energy consumption is defined as:

$$\Delta E_{total} = E_t - E_0 = \Delta E_{activity} + \Delta E_{structural} + \Delta E_{energy\ intensity} \tag{7}$$

where ΔE_{total} represents the total change resulting from activity, structural and energy intensity effects [20].

$$\Delta E_{activity} = \sum_{l} L(E_{l,t}, E_{l,0}) \ln\left(\frac{Q_t}{Q_0}\right) \tag{8}$$

$$\Delta E_{structural} = \sum_{l} L(E_{l,t}, E_{l,0}) \ln\left(\frac{S_{l,t}}{S_{l,0}}\right) \tag{9}$$

$$\Delta E_{energy\ intensity} = \sum_{l} L(E_{l,t}, E_{l,0}) \ln\left(\frac{I_{l,t}}{I_{l,0}}\right) \tag{10}$$

where $L(E_{l,t}, E_{l,0})$ is the logarithmic weighting function expressed in Equation (11).

$$L(E_{l,t}, E_{l,0}) = \frac{E_{l,t} - E_{l,0}}{\ln\left({E_{l,t}}/{E_{l,0}}\right)} \tag{11}$$

The International Energy Agency recommends using the following metrics; population as activity effect, stock per person as structural effect, and energy consumption per stock as energy intensity effect for household appliances [21]. Accordingly;

$$\Delta E_{activity} = L(FEC_{Refrigerator,t}, FEC_{Refrigerator,0}) \ln \frac{POP_t}{POP_0} \tag{12}$$

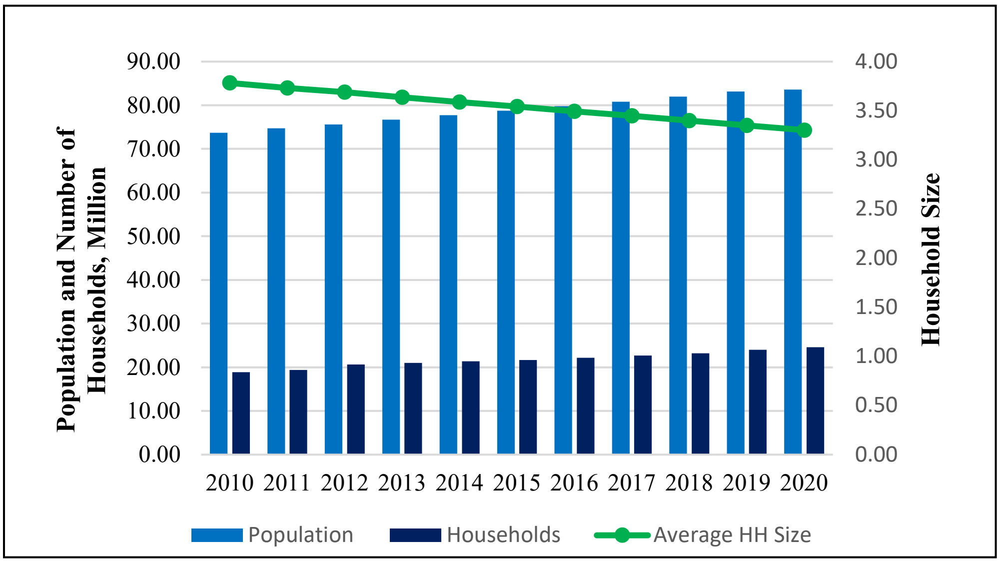
$$\Delta E_{structure} = L(FEC_{Refrigerator,t}, FEC_{Refrigerator,0}) \ln \frac{\frac{DWE_t}{POP_t}}{\frac{DWE_0}{POP_0}} + L(FEC_{Refrigerator,t}, FEC_{Refrigerator,0}) \ln \frac{\frac{Stock_t}{DWE_t}}{\frac{Stock_0}{DWE_0}} \tag{13}$$

$$\Delta E_{energy\ intensity} = L(FEC_{Refrigerator,t}, FEC_{Refrigerator,0}) \ln\left(\frac{\frac{FEC_{Refrigerator,t}}{Stock_t}}{\frac{FEC_{Refrigerator,0}}{Stock_0}}\right) \quad (14)$$

where FEC, POP and DWE denotes final energy consumption, population and number of dwellings, respectively.

Demographic statistics are obtained from the open database of the Turkish Statistical Institute [22]. The population and household statistics as presented in Figure 3 show that while the population has increased by 13.4% in the last ten years, the number of households has grown by 30.3%, more than two times the growth rate of the population.

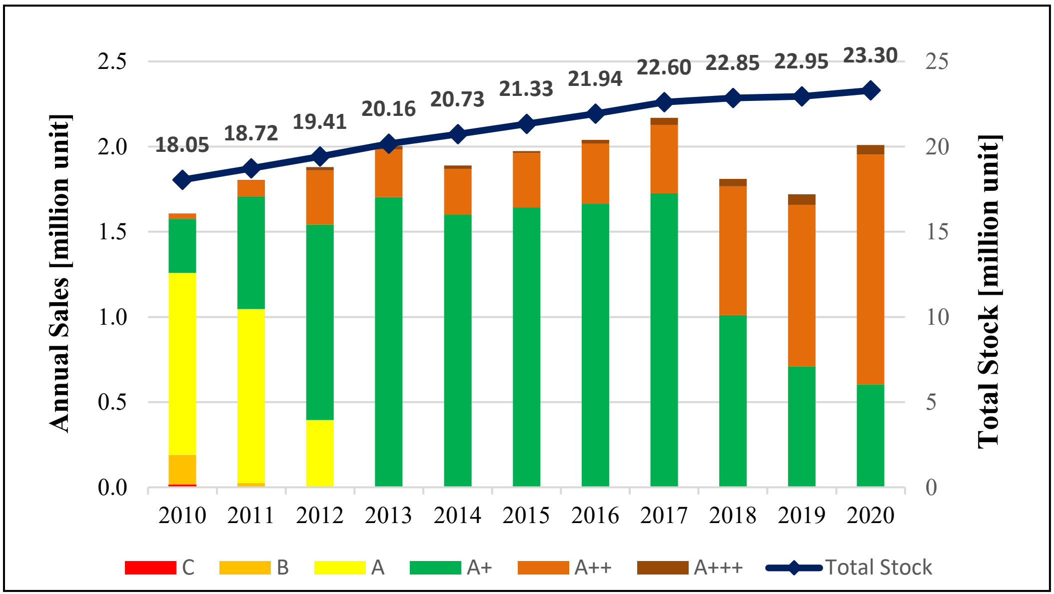
Figure 3. Demographic and social statistics for Turkey



Results

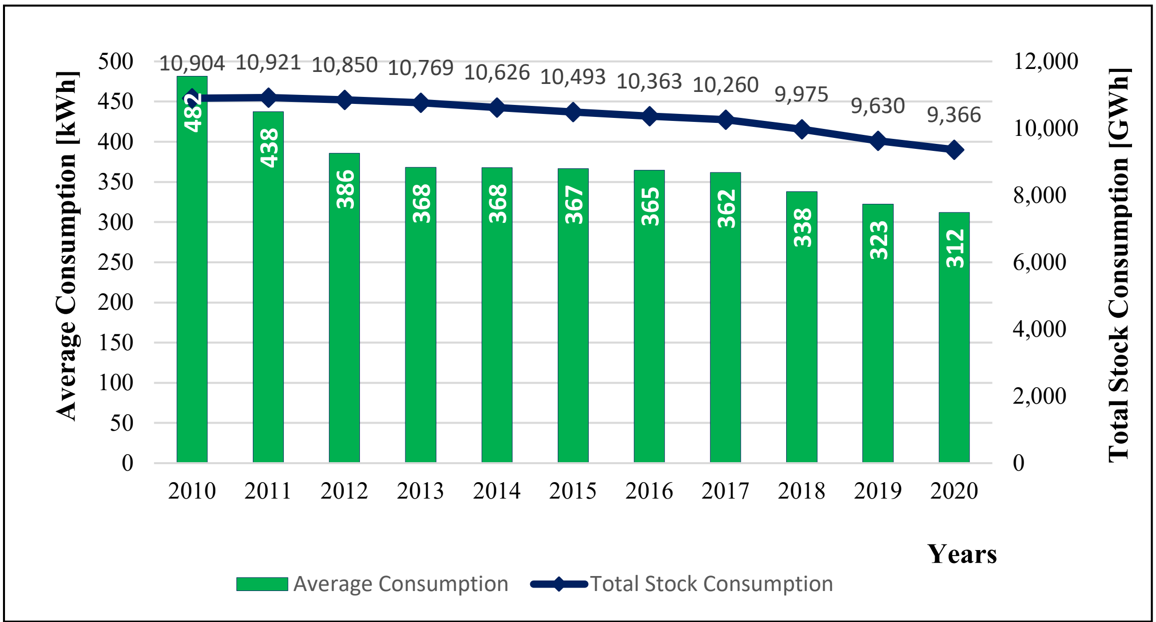
Refrigerator stock and stock energy consumption are calculated using Equations 2, 3, 4, and 5, respectively. Accordingly, the results show that refrigerator stock has increased by 29.1% in the last ten years, from 18.05 million in 2010 to 23.3 million in 2020, due to the factors such as increasing population and decreasing the average number of households. The household ownership rate is calculated by dividing the total stock by the total number of households. The results show that the household ownership rate remained constant at 96% throughout the analysis period. The obtained results are similar to Selçuk [11] and MENR [12]. Annual sales and the growth of total stock are presented in Figure 4.

Figure 4. Annual sales of refrigerators and the growth of total stock



The average refrigerator volume is assumed as 450 liters to calculate energy consumption for each energy class. Afterward, the total electricity consumption values are determined by the stock modeling approach. The total amount of electricity consumed by the refrigerator stock for 2020 is found as 9,366 GWh. As shown in Figure 5, the total electricity consumption of the refrigerator stock decreased by 14% compared to the 2010 level, despite the increase in total stock with the widespread use of efficient equipment.

Figure 5. Total electricity consumption of refrigerator stock and average consumption of refrigerator sales



The average energy consumption of refrigerator sales decreased by 35%, from 482 kWh in 2010 to 312 kWh in 2020. On the other hand, the effect of the minimum efficiency levels introduced in 2012 is quite evident. While the average consumption of sales was 438 kWh in 2011, this value declined steeply to 386 kWh in 2012. Although a stable picture is observed in the 2012-2017 period, the improvement in the average energy consumption of sales after 2017 is striking. Along with many other factors, it is considered that the tax reductions applied in the 2018-2019 period may also contribute to this situation.

The main determining factor in the amount of energy savings achieved by replacing efficient refrigerators during the analysis period is the significant improvement in the energy efficiency of refrigerators. However, some of the savings may have been lost for different reasons, such as the increased welfare of households, leading consumers to prefer refrigerators with larger volumes. For this reason, it is very important to analyze the factors causing the increase and decrease in energy consumption in detail.

According to the decomposition analysis results performed with the additive type LDMI method, 1,274 GWh was added to the total energy consumption of the refrigerator stock in the last ten years due to the increasing population. In addition, 1,371 GWh was added to the total energy consumption due to the decrease in the average number of households. It has been observed that the welfare effect does not contribute to total consumption over the years, and it reduced only 64 GWh of electricity consumption. Due to the efficiency increase in refrigerators, 4,120 GWh of energy was saved. In Figure 6, the activity, structural, and productivity effects are shown as an index, taking 2010 as a reference. If there were no improvements in energy efficiency, the energy consumption of the total refrigerator stock would have been 13,485 GWh, 44% higher than the value in 2020, as presented in Figure 7.

Figure 6. Yearly additive decomposition results 2010-2020 (% in terms of 2020 FEC of Refrigerators)

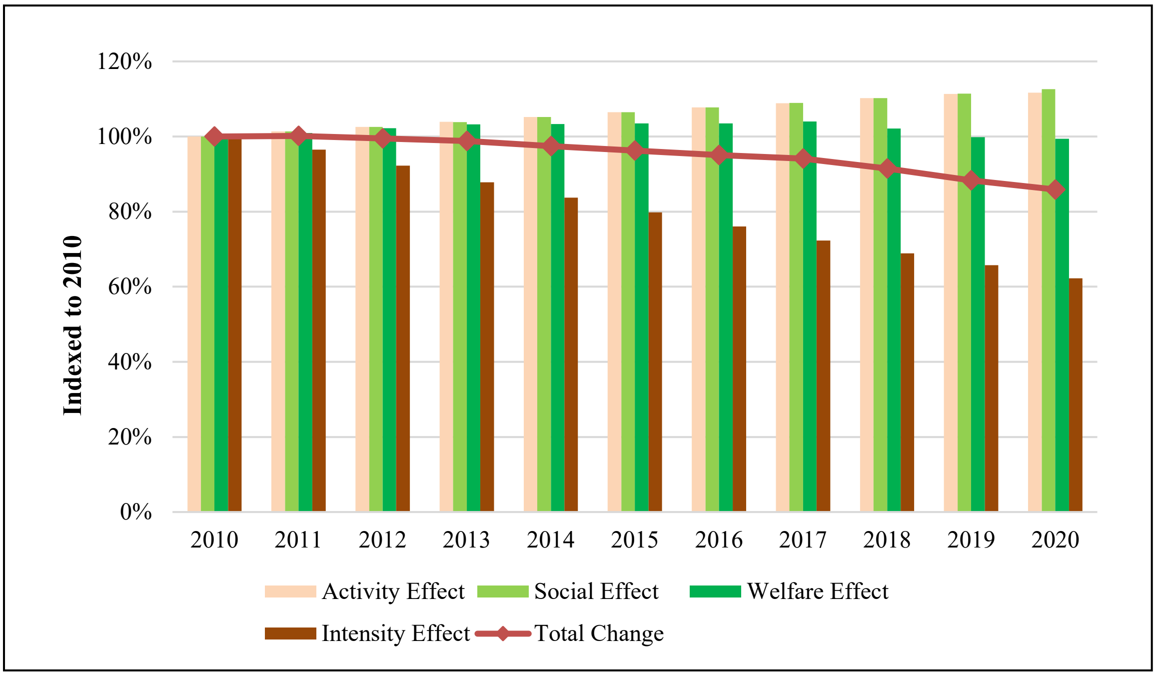
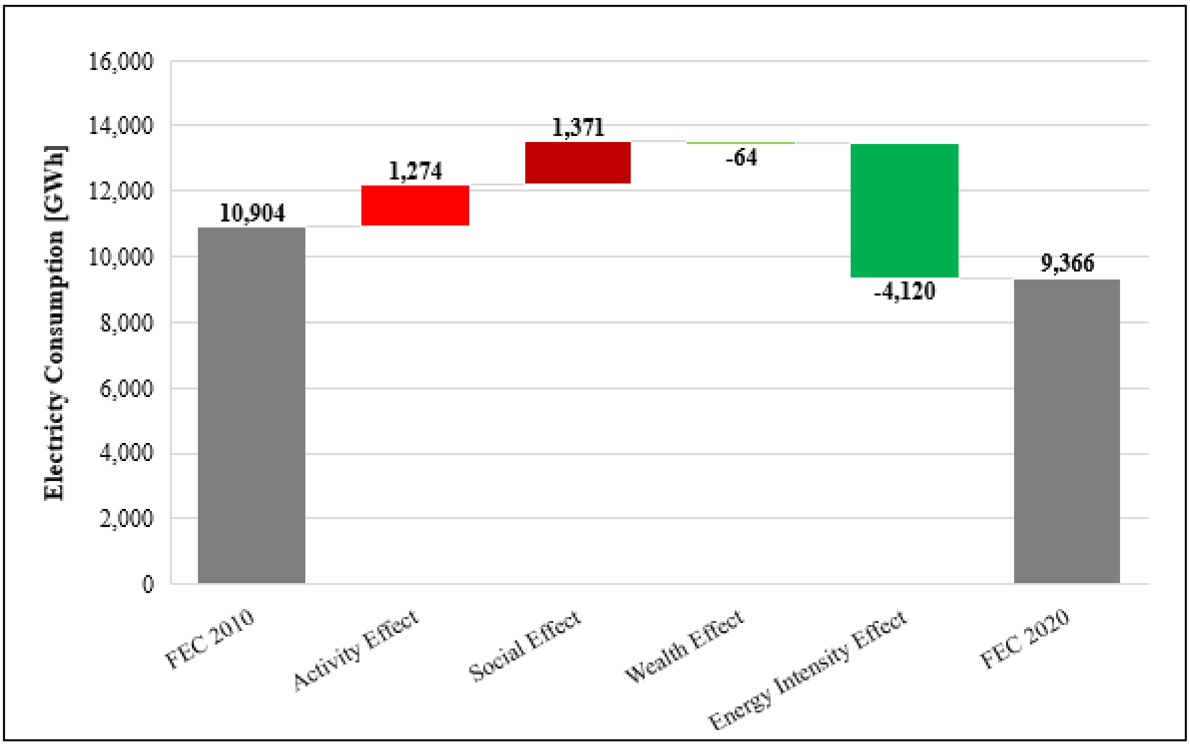


Figure 7. Decomposition of changes in final energy consumption, 2010-2020.



Conclusion

Since energy efficiency is at the center of net-zero climate targets, developing necessary data sets to guide decision-makers is extremely important to produce data-based policy options. However, this generally requires costly and time-consuming energy audits and surveys by taking samples that represent the whole socioeconomic classes of the society with sufficient sensitivity. As another method in case of limited data, stock modeling and decomposition analysis approaches can be employed as a cost-effective solution to get a general framework on the energy consumption profile and an idea of the effectiveness of the policies and programs through macro indicators.

In this study, the total refrigerator stock and its energy consumption in residential buildings were determined by employing the stock modeling approach. According to the analysis results, the refrigerator stock has increased by 29.1% in the last ten years, reaching 23.3 million in 2020, due to the increasing population and the decreasing average number of households. The electricity consumption of the total stock in 2020 was calculated as 9,366 GWh. This value corresponds to approximately 16% of the electricity consumption of the residential sector in Turkey. Looking at the average energy consumption of the refrigerators sold by years, average energy consumption is observed to decrease from 482 kWh in 2010 to 312 kWh in 2020. The effects of eco-design and labeling regulations are clearly seen after 2012.

The decomposition analysis methodology allows one to understand the main drivers behind the increase in energy consumption and the effectiveness of the policies and programs put into practice. For this purpose, the LDMI-I approach was used to determine the savings achieved by increasing the efficiency of refrigerators and the effectiveness of the implemented programs during the analysis period. According to the decomposition analysis results, the total energy consumption of the refrigerator stock would be 13,485 GWh, with a 44% increase if there was no improvement in energy efficiency. Due to the increase in energy efficiency, energy savings of 4,120 GWh were achieved. During the analysis period, the increase in the population and decreasing average number of households caused stock consumption to increase by 1,274 GWh and 1,371 GWh, respectively.

As a result, stock electricity consumption decreased by 14%, mainly due to improvements in energy efficiency, although the stock increased by 29%. The effect of the eco-design and labeling communiqués coming into force in 2012 and the incentive programs implemented in the 2018-2019 period are evident. It is seen that the transformation of the market into efficient household appliances has taken place with the regulations and incentives. However, if the cost and time constraints are eliminated, the actual appliance stock and the appliance electricity consumption would be determined using long-term measurements and energy audits. This would enable detailed analyses, including the seasonality effects on appliance electricity consumption.

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After 25 years of European Eco design and Energy Labelling Regulations: where do we stand today? In-depth scan of the French household electricity consumption

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Abstract

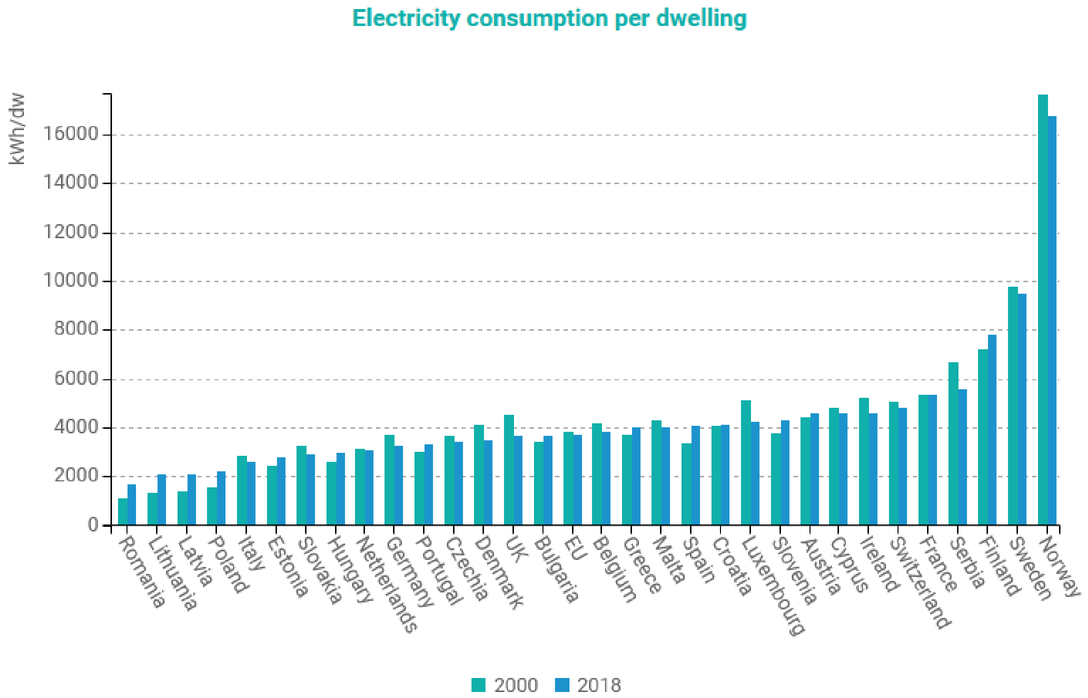
France has the fifth largest electricity consumption per household in the EU-27. In this context the French Energy Agency (ADEME) and the French Transmission System Operator (RTE) have decided to fund together the PANEL ELECDOM project. It aims to provide yearly an accurate household electricity consumption baseline dataset. To achieve this goal, 2 500 connected sensors have been installed in the electrical panel or directly on appliances in a representative sample of one hundred French households since April 2019. It contributes to a better understanding of how electricity is consumed in French dwellings and where the main challenges remain.

The paper gives an analysis of the data collected during the first year of this monitoring program. It provides valuable insights on the French residential electricity consumption, its key drivers and its precise breakdown among end-uses. Eighty different types of equipment are covered, including some that have never been audited before like home automation, medical device, and electric mobility. This in-depth study highlights trends in the evolution of electricity consumption over the last twenty-five years. It assesses the impacts of recent technological developments (e.g., LEDs, heat pumps) and of fast-growing uses (e.g., electric mobility, air conditioning, private swimming pool). It also gives valuable answers to questions related to the European Eco design and Energy Labelling Regulations: how efficient has the process been so far? Are there still any improvements possible? Are there any high-consumption devices that are not regulated?

Introduction

The level of electricity consumption per dwelling in Europe is very unequal partly due to its thermal uses (space and water heating) and climate. France has the fifth largest electricity consumption per household (figure 1).

Figure 1. Electricity consumption per dwelling in Europe – Source: Odyssee-mure[264]



Today nobody knows precisely how the electricity consumption of an average household is disaggregated by device type. This lack of knowledge affects the capacity to implement pertinent actions in order to reduce it. Most of the prospective demand-side management studies are based on stock accounting models and not on field measurements. They do not take into account the continuous emergence of new equipment, the real use of the appliances or the behaviour change (impossible to simulate, solely observable) that have a major influence.

Based on this observation, the overall goal of the PANEL ELECDOM project, financed by the French Energy Agency (ADEME) and the French transmission system operator (RTE), is to improve the knowledge of electricity consumption in the French residential sector. It is the biggest consumer in 2017 with 33% of the overall French electricity consumption. The intention is to provide reliable information and data on the French household electricity consumption that is annually updated. Based on information gathered directly in actual households, this unique research study is intended to evaluate dynamically the impact of societal changes and consumption patterns.

This paper covers the first year of data collection (April 2019 to April 2020). This first analysis is not fully representative of the average consumption as the measuring period includes one month of lockdown (15th of March to 15th of April 2020), which represents 8 % of the total length of the study.

Method

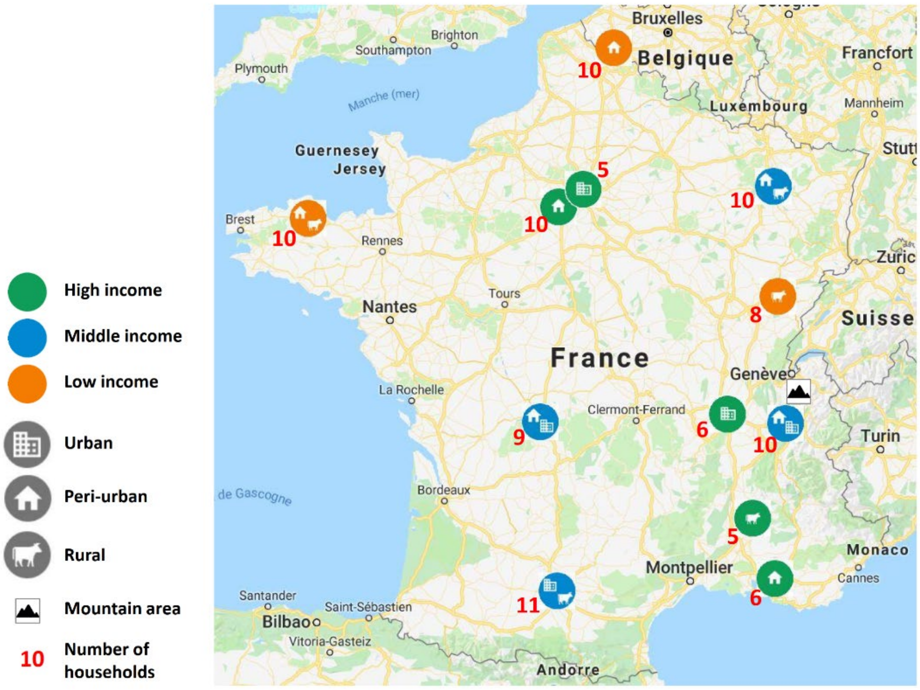
Sample

The sample of one hundred households has been randomly selected within a large community of active members of an Internet access panel (pre-screened respondents who have expressed a willingness to participate in surveys and/or customer feedback sessions). This choice appears to be the optimum between accuracy and acceptable cost of implementation. An internal statistical study [1] showed that the order of magnitude of the uncertainty when estimating values over the entire French population with a sample of 100 units is approximately 10%.

[264] https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html

The map of figure 2 indicates the location and the characteristics of the households in the different selected zones.

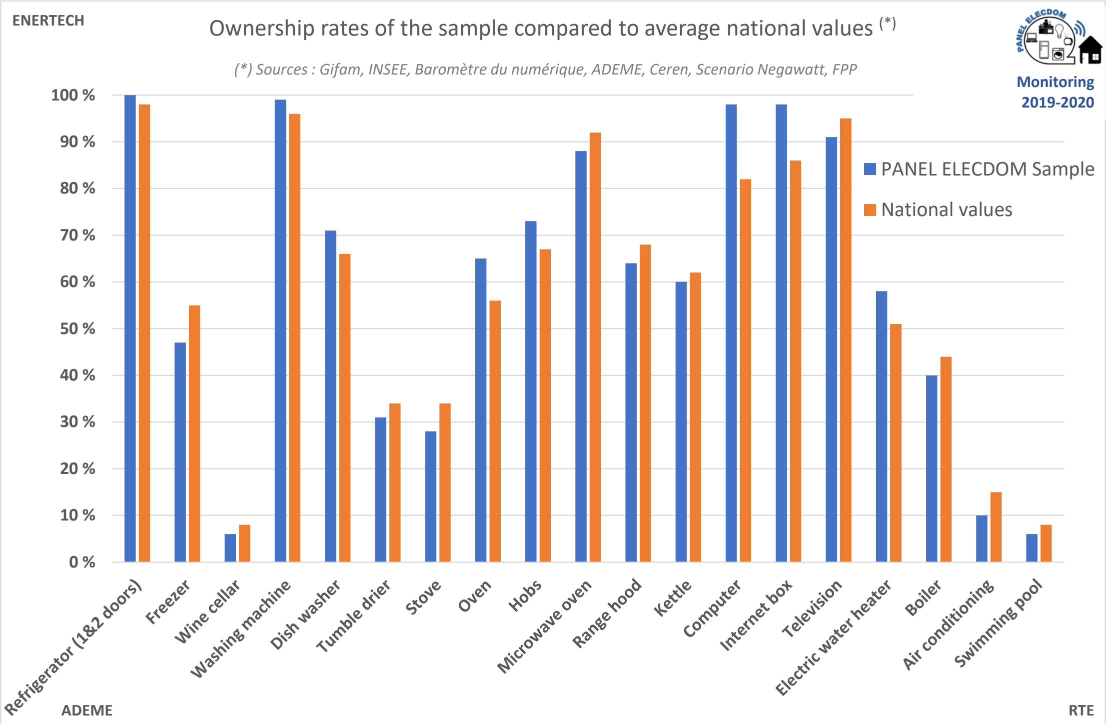
Figure 2. Location and characteristics of the recruitment zones (centred on Roubaix, Guingamp, Paris, Lyon, Rambouillet, Nancy, Besançon, Limoges, Chambéry, Aix-en-Provence, Toulouse)



The sample's composition is very close to the average national values: 55% are individual homes, 33% of the dwellings are heated with electricity and the average surface area is 92 $m^2_{living\ area}$[265]. There is a slight over-representation of families of 4. The households of the sample also have an equipment level similar to the average national values (figure 3).

[265] National average values: 56% individual homes (INSEE, 2016), 34% electrically heated (CEREN, 2016), 91 $m^2_{living\ area}$ (INSEE, 2013). More information can be found at https://librairie.ademe.fr/changement-climatique-et-energie/4473-panel-usages-electrodomestiques.html

Figure 3. Ownership rates of the sample compared to the average national values

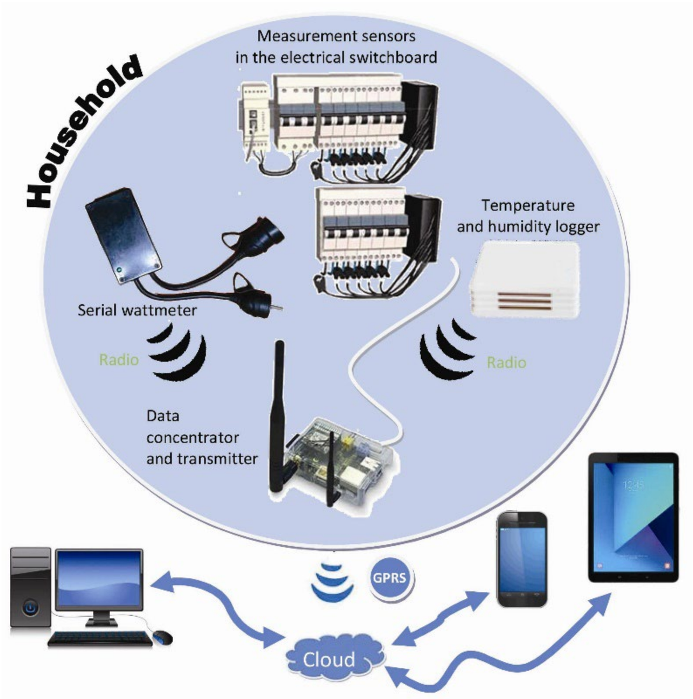


Metrology

In each of the 100 households of the sample, a communicating system records every 10 minutes the energy consumption of most appliances that are plugged both into the electrical sockets and on the main outlets of the electrical panel. The data are sent daily to an FTP server. Every dwelling is equipped with approximately 25 measuring points. The whole monitoring infrastructure is schematically presented in figure 4[266].

266 More information can be found at https://librairie.ademe.fr/changement-climatique-et-energie/4473-panel-usages-electrodomestiques.html

Figure 4. Monitoring, data transmission and storage process



On-site Inventory and online questionnaire

Carried out at the same time as the sensors' installation, the inventory of all of the household equipment allowed for numerous technical information to be gathered. It listed the appliances and their characteristics (reference, year of purchase, rated power, settings).

An online questionnaire (60 questions) was also sent to every participant at the very beginning of the campaign in order to establish the link between the attitudes and the consumption.

Results

Overall electricity consumption

The average electricity consumption per household (all uses combined) is equal to 4 792 kWh/year, i.e. 54 $kWh/m^2_{living\ area}$/year. This value is very close to the 4 888 kWh/year/household given for 2019 by the French Ministry of Ecological and Solidarity Transition [267]. The specific electricity consumption (that includes all uses except heating, hot water and cooking) has been measured at a level of 2 228 kWh/year, i.e. 25 $kWh/m^2_{living\ area}$/year.

The main factors that would explain the household electricity consumption are (starting with the most important one):

- The surface: the consumption in terms of kWh per m² surface remains almost unchanged regardless of the size of the dwelling. There is a slight downward trend for very large dwellings (>150 m²).

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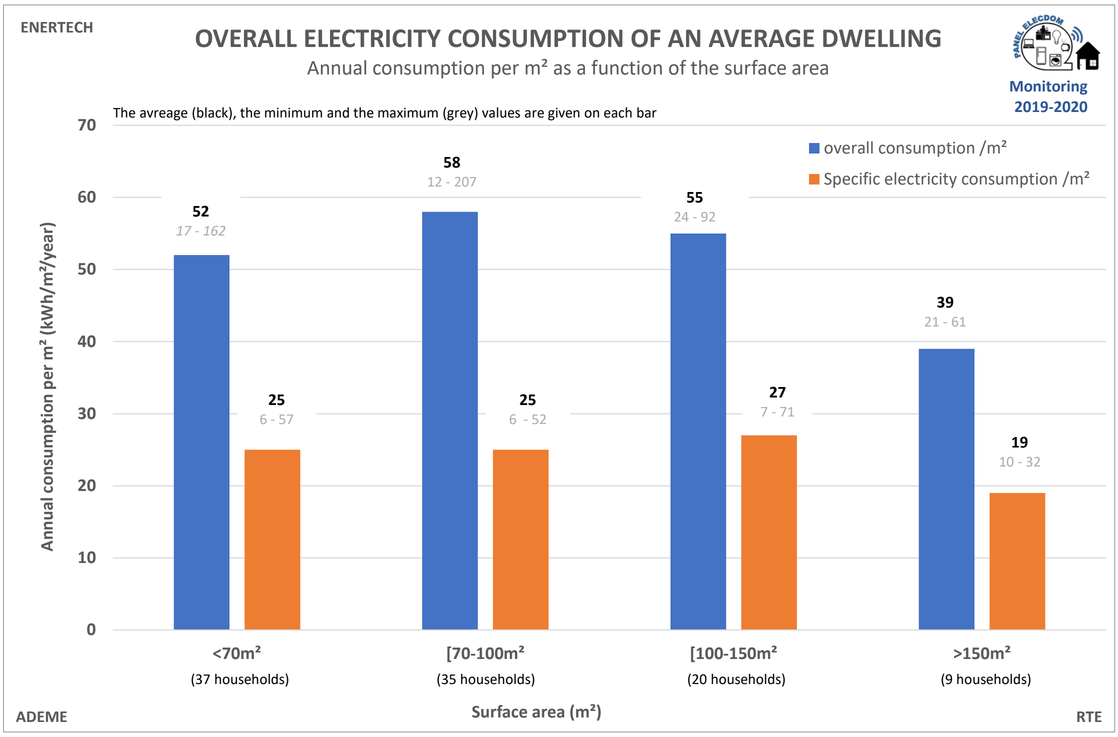
[267] https://www.statistiques.developpement-durable.gouv.fr/consommation-denergie-par-usage-du-residentiel

Figure 5. Histogram of the annual consumption as a function of the living area



- The household typology: "small" electricity consumers (single people, couples without children, single elderly people and one-parent families) and "big" (elderly couples, couples with child(ren)).

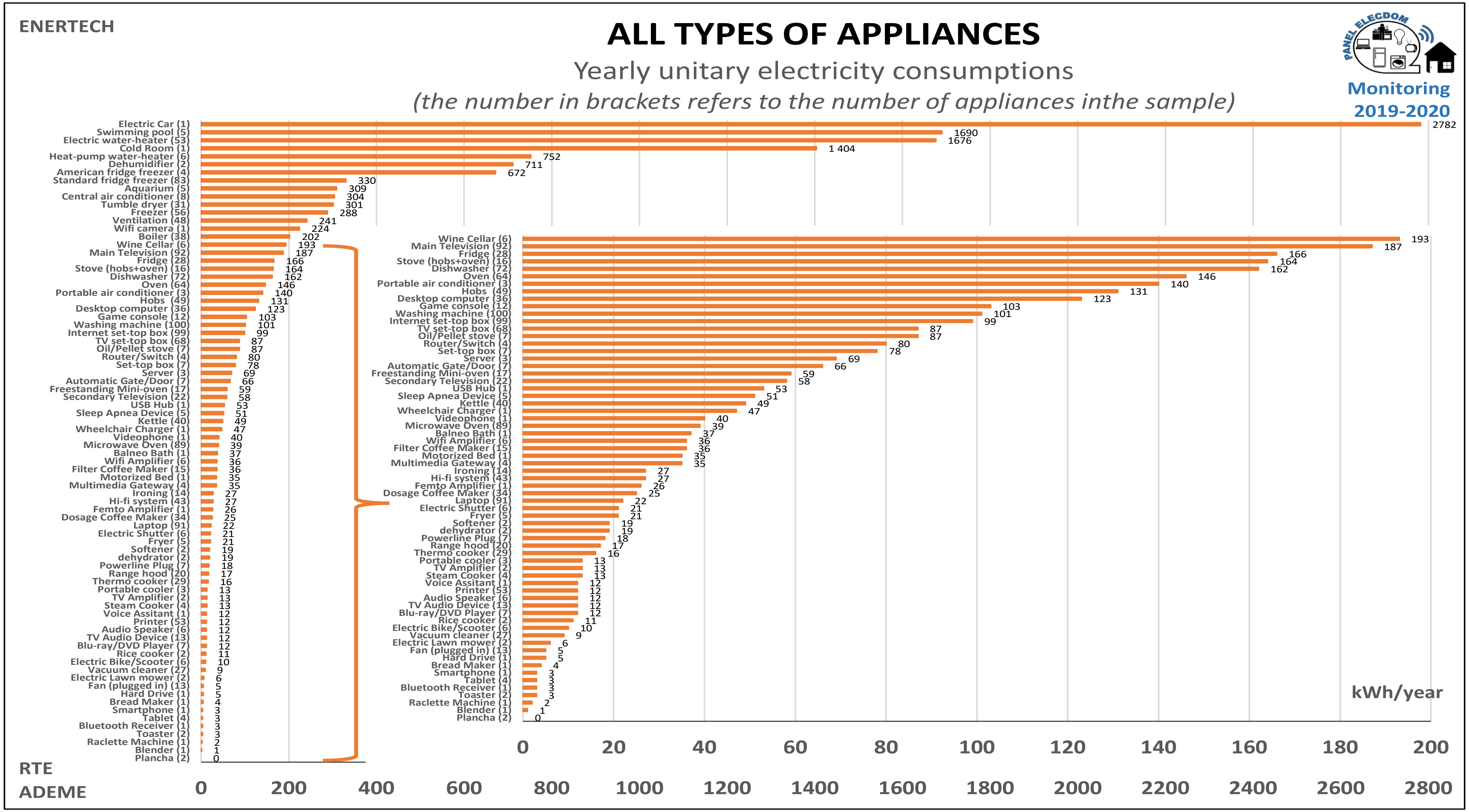
- The income: the correlation is less pronounced when watching surface consumptions showing that the highest the income, the largest the floor space.

Ranking of the consumptions of the different household appliances

The following graph shows a ranking of the average consumption for the 80 different types of equipment that have been monitored. This does not include electric heating. Except electric water heaters, the appliances that consumed the most energy are installed only in a small number of dwellings (electric car, swimming pool, cold room, dehumidifier).

On the opposite end, more than two thirds of the monitored appliances consume less than 100 kWh/year.

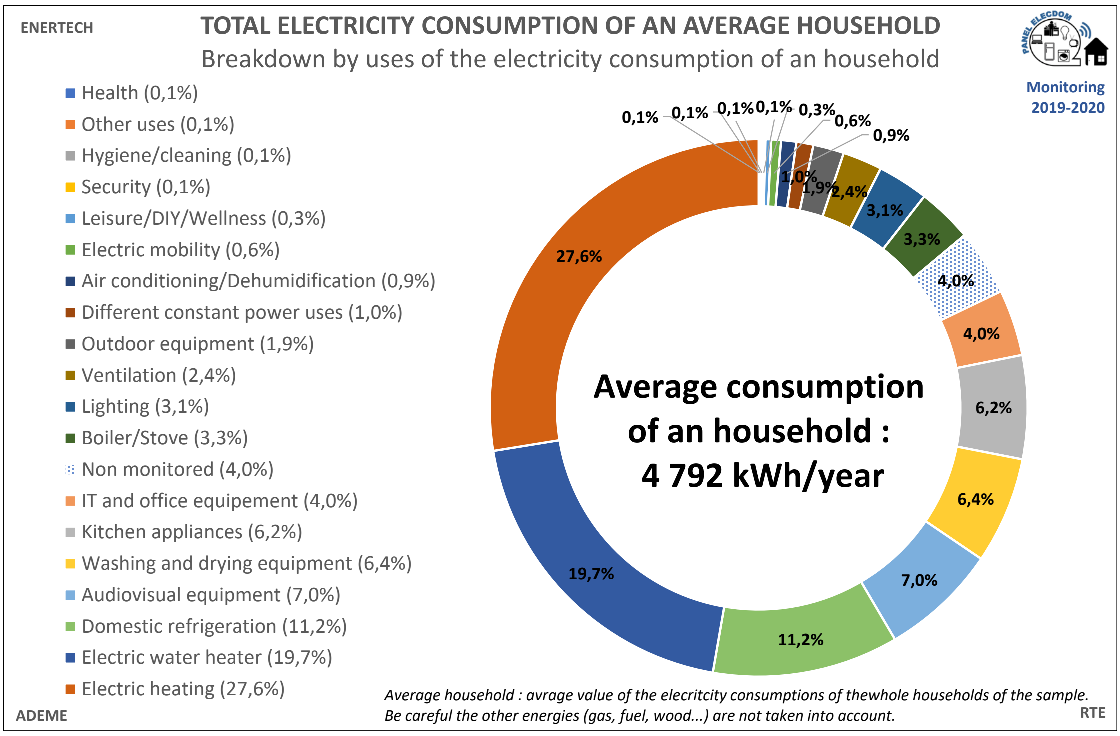
Figure 6. Yearly unitary electricity consumptions of the different monitored appliances



Distribution of the consumption between the different uses

As shown in figure 7, the thermal use of electricity, heating and hot water, represents almost half of the total electricity consumption (47.3%). Cold appliances were, historically, the appliances which used the most energy and it is still the case today, followed by audiovisual devices. Lighting, which has been for a long time one of the highest consuming areas, has seen its consumption drop drastically. This monitoring campaign also shows the substantial weight of ventilation, boilers and outdoor equipment (mainly swimming pools). Even though they represent a significant part of the overall consumption, they are today usually not taken into account in the electricity balance. Air conditioning and electric mobility are emerging but their impact is still very limited. The average rate of non-monitored appliances (2.5% without taking into account the electricity consumption of the measuring devices) is largely under the goal set for this project (a maximum of 10 % of undetermined consumptions).

Figure 7. TOTAL ELECTRICITY CONSUMPTION / ALL USES COMBINED – Distribution of the electricity consumption of an average French household between the different uses.



Main findings for the different uses

The analysis of the consumption of large sample of equipment is particularly rich in teachings. In this paragraph we outline the evolution of technical features and of the electricity consumption for the main equipment. We always refer to the previous energy labels which were valid until March 21.

Electric water heater

With 61 dwellings equipped, and a measured consumption of 1,582 kWh/year per equipped dwelling (resistance water heater or water heaters with electrically driven compressor), electric water heater is a major item of the domestic electrical consumption in France. According to our measurements, it is equivalent to 70% of the national consumption of electric heating.

The storage joule-effect water heater is still the main producer of electric DHW, covering about 90% of the whole electric water heaters and 95% of consumption. Its average annual consumption is 1,676 kWh per appliance, which represents 30% of the total electricity consumption of equipped households.

Storage water heaters with electrically driven compressor, whose sales have increased in recent years, are still in the minority with 6% of the equipment rate according to our sample[268]. This equipment consumes 2.2 times less than joule-effect water heaters (752kWh per dwelling equipped). The analysis of the data shows surprisingly that the back-up electrical element consumes on average 27% of the total electricity consumption.

Cold appliances

The electricity consumption continues to decrease mainly for the single-door fridges and the freezers and, to a lesser extent, for the double-door refrigerators. Savings are still possible because there are still not so many efficient appliances: the sample contains between a quarter (2-door refrigerators) and a third (single-door fridges and the freezers) of class A and less efficient, 49% of class A+ and only one class A+++. Almost three-quarters of the sample are tropical (T) or subtropical (ST) appliances[269]. Indeed, climate class correction factors are applied when calculating the energy efficiency index (EEI) and manufacturers probably use them to get a better energy class. The consumption of the whole household cold appliances is no longer decreasing (only -1% compared to 2015 [2]). One possible explanation could be the constant increase for 25 years of the average number of cold appliances by household (1.8 by household in 2019 versus 1.4 in 1996) that counterbalances the energy efficiency improvements.

Audio-visual devices

60% of the televisions of our sample are LED models. The average size of a screen is 39 inches which represents an increase of 34% compared to 2008 (29 inches in the REMODECE project [3]). Their average daily operating time is now 6 hours and 46 minutes, i.e., 50 minutes more than in 2008 (REMODECE) and 1 hour 46 minutes more than in 1998 (ECUEL monitoring campaign [4]). The best available technology (Direct LED backlight) consumes 1.6 times less than LCD backlight tubes.

The TV set top box is wide scale equipment in French household (71% of our sample own one) and 64% of its consumption corresponds to the TV set box operating when the television is off.

The electricity consumption of gaming consoles has increased by a factor 5 since 2008 (REMODECE). However, their time of use varies greatly from a household to another. 35% of our sample have at least one.

Washing and drying appliances

After an important decrease between 2008 and 2015, the electricity consumption of washing-machine remains now stable, even though the large proportion of very energy efficient appliances (36% of class A+++). The per-cycle consumption is still going down but the number of cycles, mainly the cold ones, is getting higher. During the last 5 years the average capacity of the appliances has also gained about 1 kilogram.

The trend is the same regarding the electricity consumption of dishwashers.

More than half of the tumble dryers are rated 8 kilograms or more and the biggest devices are the most recent ones. Two-third of the appliances are still class B or worse. The most efficient tumble dryers are equipped with a heat pump which allows a reduction of the consumption of an average cycle by 1.9 compared to condensation dryers and by 2.4 compared to exhaust air dryers. But the cycles last longer with a heat pump.

Cooking appliances

This subset contains numerous appliances which unitary consumptions are very low, except hobs, ovens and stoves. Electricity consumption related to cooking is very similar to the one measured in France in 2014 (Wattgo study [5]). The savings during the last 15 years are far less important than for cold and washing appliances.

Hobs are used on average 7.9 times a week and ovens 3.6 times a week. Induction hobs consume on a yearly basis 11% less than radiant models (-19% if considering consumption per cooking cycle).

[268] National average value: 4% (Gifam, 2021).

[269] Climate classes indicate the minimum and maximum temperature limits, within which the refrigerators are able to operate properly.

IT equipment

Residential IT equipment consumes 1.8 times less than audiovisual equipment. The major contributor is the Internet set top box which draws continuously on average 11.7W. The power varies according to the functionalities (4K, NAS server, Wifi activation…). The more recent the box, the more services they propose and the higher their electricity consumption is. The most recent ones are around 20W which is equal to the average active power of a laptop.

The electricity consumption of the laptops has decreased by a factor 1.6 since 2008 (REMODECE). Indeed, we have monitored that the power of laptops that are 10 years old and more is 2 to 3 times higher than the laptops that are less than 5 years old. This is due to the improvement of processors and power scaling (multi-core) and the use of LED technology for screens.

The consumption of desktop computers (including monitor/display) has decreased by a factor 2.3 since 2008 (REMODECE) but it is still 5.3 times more than the electricity consumption of laptops. Both their power (division by a factor 1.6 since 2008) and time of use (3 hours 54 per day against 6 hours 30 in 2008) have decreased.

Lighting

The average lighting consumption is 147 kWh/year/household[270]. It has decreased by a factor 2.5 since 2004 ("Eclairage 100" French monitoring campaign [6]). The installed power has been reduced by a factor 2.2. The number of light sources per household has not changed during the last fifteen years but a shift from banned incandescent to LED technology (48% of the lighting sources of the sample) has been operated. The number of inefficient halogen sources is still high, probably because they first replaced incandescent bulbs before the large diffusion of LEDs at an affordable price. It illustrates the positive impact of the EuP directive. This trend has probably been amplified by the French White Certificate Scheme that gives bonus to efficient lighting.

Auxiliaries (Ventilation and non-electric heating)

48% of our sample homes have a central ventilation system. Only one is an exhaust and supply air ventilation with heat recovery while all the others are single-flow installations. In 84% of the equipped households, it has run more than 95% of the year and in only 4% it has never run. The measured ventilator powers are very different from a household to another but the main explanatory factors (flowrate, pressure losses, air leakage) have not been monitored.

The electric consumption of oil/gas fired boiler varies over an 18-fold range. These differences are mainly explained by the type of control of the circulator and to a lesser extent by its efficiency. The standby state covers on average 16% of the total consumption. Since 2015, the European Ecodesign Directive applies to boilers. This directive could be improved by imposing a constraint on the maximum standby power (as it is already the case for many household appliances) and by making the control of the circulator operation by the boiler burner mandatory.

Air conditioning

Only 10% of the dwellings in the sample, mainly located in southern France, are equipped with a fixed air conditioning system and 3% have a mobile air conditioner. The operating time is very different from one dwelling to another. Air conditioning still accounts for less than 1% of the total residential electricity consumption.

Miscellaneous

An electric car was monitored. Its consumption equals 2,782 kWh/year, i.e., 32% of the electricity consumption of the dwelling concerned (electric water heater and electric heating as a back-up to a boiler). Other electric

[270] Lighting is monitored in the electrical panel and on plugs if electrical consumption of a floor lamp is estimated at more than 20kWh/year (rated power multiplied by the estimated operating time)

mobility devices (5 bikes, 1 scooter,1 hoverboard) were instrumented. Their average consumption is only 10 kWh/year.

The average consumption for swimming-pools is close to that measured in 2006 [7]. It does not seem to be directly linked to the volume of water but is rather explained by the (over)sizing of the filtration pumps as well as by their operating time, that often exceeds what is actually needed.

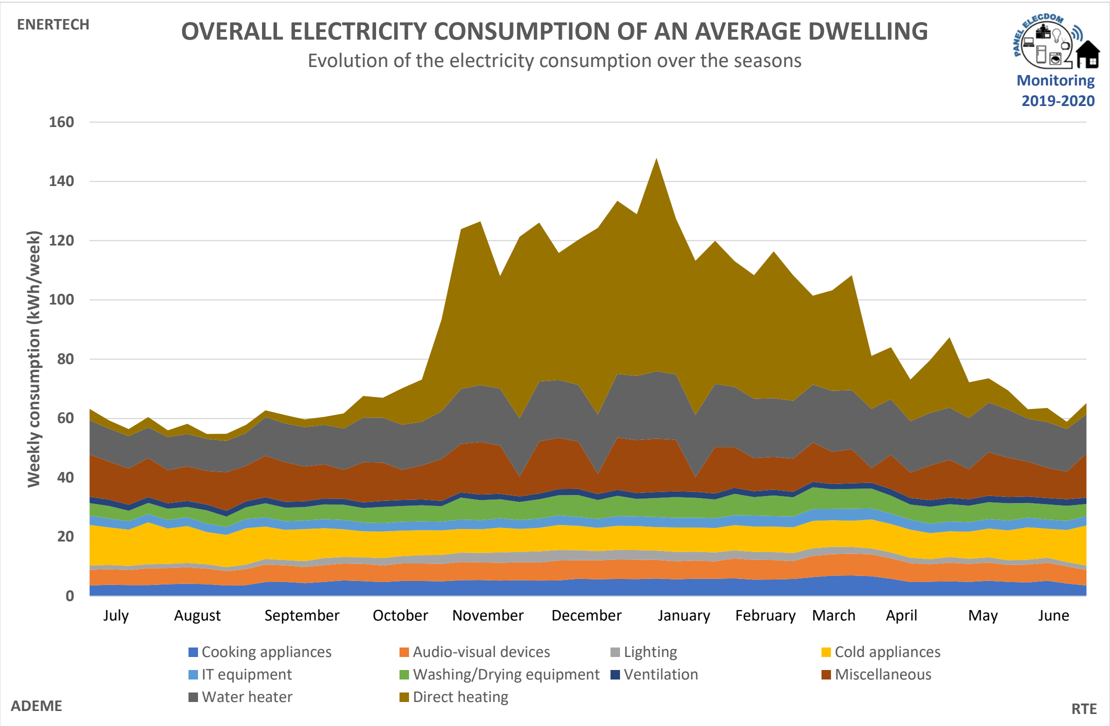
The average consumptions measured for ironing and floor cleaning are low. They are of the same order of magnitude as those found in 1995 (Ciel measurement campaign [8]). However, very few appliances were instrumented; the values must therefore be considered with caution.

This measurement campaign also highlights the importance of the consumption of security devices (automatic gates, WiFi security cameras and, to a lesser extent, roller shutters). For example, the average annual consumption of an automatic gate is 3 times higher than the one of a laptop. Indeed, no regulation currently applies to them which means that no limit on stand-by power is set.

Seasonality of consumption

The thermosensitivity of French residential electricity consumption is very high. It is mainly due to the predominance of electric space heating, which explains the existence of a factor greater than two between consumption in summer and winter. The production of domestic hot water is also very seasonal. Other specific uses form a base without pronounced seasonal variations. Some uses, such as ventilation or IT equipment, draw the same power all year round. Others, such as cold appliances, have a higher consumption in summer. They are balanced by those with an opposite consumption profile (audiovisual, lighting, washing/drying).

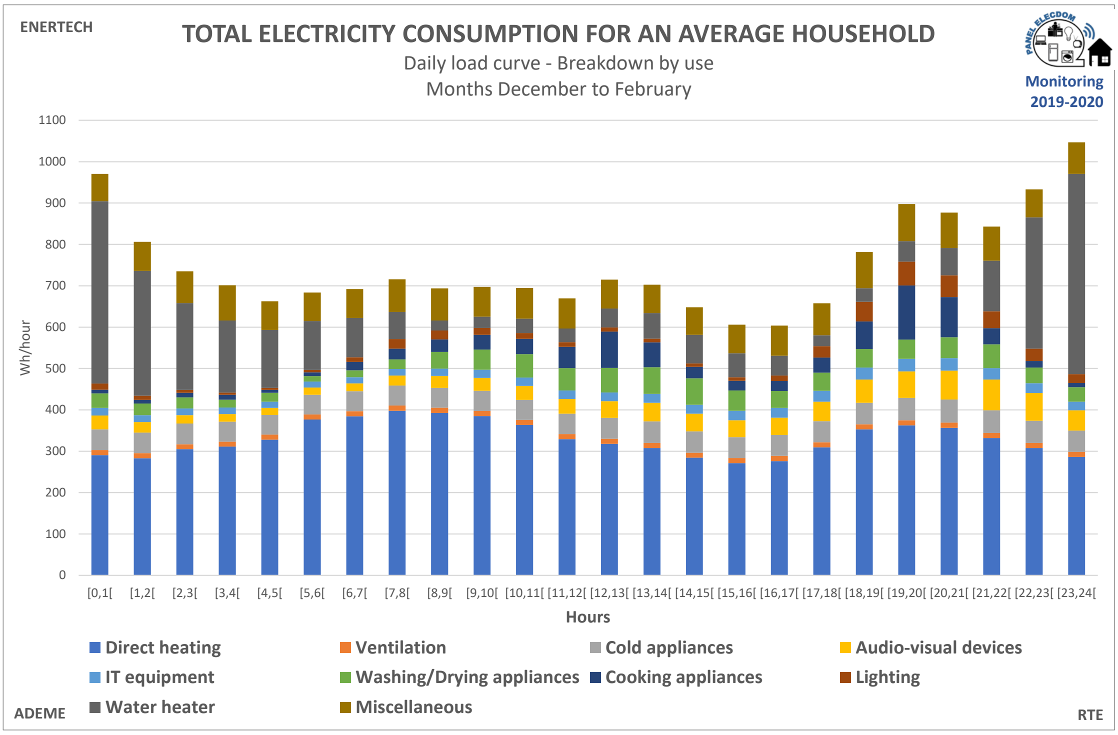
Figure 8. Breakdown and evolution of the total electricity consumption all along the year



Daily load curve

Although there is still a consumption peak around 7 p.m. when considering all sectors together, it is no longer very visible for solely the residential sector (figure 9). In the past, the 7 p.m. peak was due to the switching on of numerous electrical appliances, mainly lighting and cooking equipment. In winter, there is now rather an "upper plateau" between 19:00 and 01:00. The peak in consumption occurs between 23:00 and 00:00 and corresponds to the simultaneous start of many water heaters operating in off-peak hours (low nighttime tariff for electricity).

Figure 9. Breakdown and evolution of the total electricity consumption for a typical winter day



Discussion

The project Panel Elecdom enables a better understanding of how electricity is consumed in French homes and where the main challenges remain. Using these observations, it is possible to shape actions to efficiently reduce the electricity consumption in the residential sector.

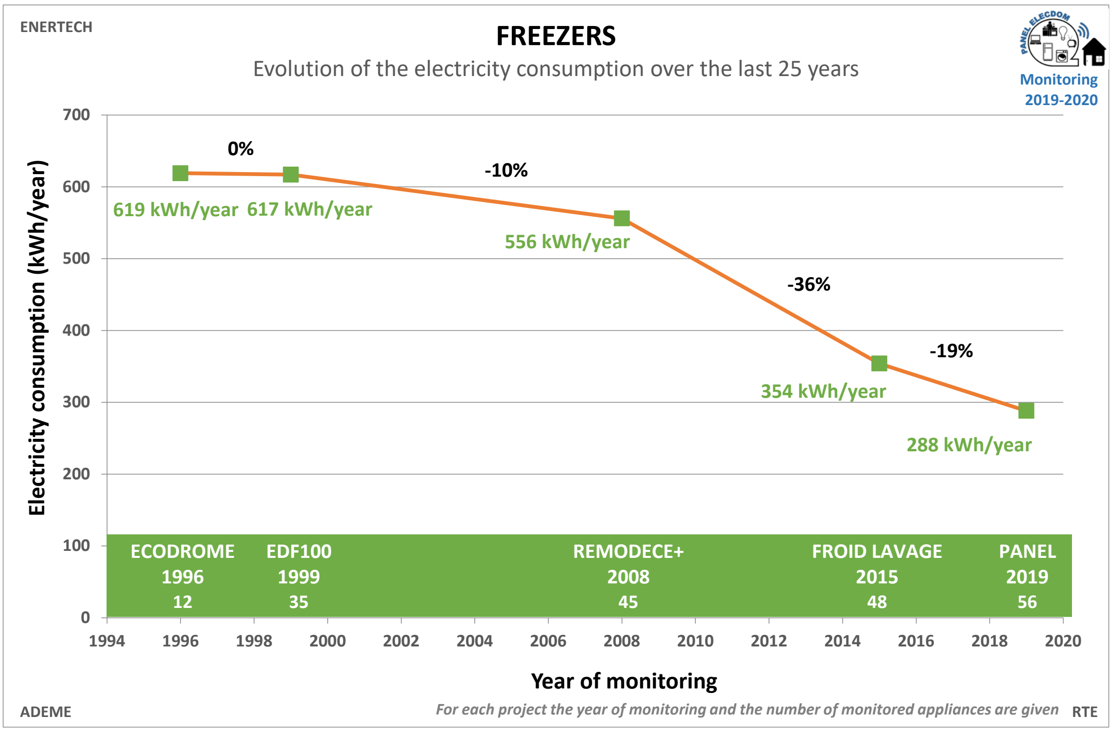
The following conclusions can be drawn from this study:

1- the electricity consumption of private households in France is dominated by space and water heating. Policy should focus on increasing energy efficiency for these uses, e.g., with better building insulation, heat pumps for heating of space and water (instead of direct electric) and strengthen solar energy.

2- The European regulatory system has worked very well, and has allowed for a drastic reduction of electricity consumption over the last 20 years to take place, as shown for example for freezers on figure 10[271]. However, it appears that it is reaching its limit as the first regulated uses (cold, cleaning and cooking appliances) have seen their consumption stabilize, mainly because of non-technological reasons (increase in the ownership rate, in the size and capacity of devices, etc.).

[271] The evolution of the electricity consumption over time for other appliances can be found at https://librairie.ademe.fr/changement-climatique-et-energie/4473-panel-usages-electrodomestiques.html

Figure 10. Evolution of the electricity consumption of freezers between 1996 and 2019



3- In the meantime, technological advances such as the mass roll-out of LED (lighting and screens) and the use of heat-pumps (water heaters and dryers) have enabled great consumption reductions.

4- Certain uses such as electric cars, air conditioning or private swimming pools have become more widespread. However, they still have a limited impact on total residential consumption. In the future, their contribution to total electric consumption could become more important if their penetration continues to increase.

5- Certain European regulations (boilers, water heaters, cooking appliances) could be improved to further reduce electricity consumptions.

6- The level of power used in the different states (on, off, standby) by various devices (set-top boxes, heating auxiliaries, house automation, connected objects) could also be regulated at the European level.

7- Simultaneously, regulatory measures could be set up, at a national level, regarding the power draw of individual swimming pools, air conditioning, ventilation systems, water heaters and boilers.

8- This study has made it possible to define the devices making major contributions to household electricity consumption. However, particular appliances (tumble dryers, ventilations, dehumidifiers, storage water heaters with electrically driven compressor) would require a complementary study to deepen the knowledge and then derive possible solutions to reduce their consumption.

9- Targeted actions to boost the uptake of heat-pump water heaters and tumble dryers could be implemented. Other measures regarding the controls setting optimisation on boilers or swimming pool pumps could also be proposed.

10- Public-awareness messages (eco-friendly behaviours) could be updated using the knowledge gained from this study.

11- Lastly, a more general survey could be conducted to establish the ownership rate of the different electrical devices in order to confirm the distribution of electricity consumption of an average dwelling between the different uses.

Acknowledgements

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Environmental Dumping of comfort fans in Europe

Hélène Rochat, Topten

Maike Hepp, Topten

Eric Bush, Topten

Abstract

Comfort fans - together with air conditioners - are regulated by the European Commission Ecodesign Regulation (EU) No 206/2012. However, unlike most Ecodesign regulations, comfort fans are only subject to information requirements and are not subject to any requirements on energy efficiency. As the revision of the Ecodesign and Energy Label regulation for fans is taking place on the European level, it is being considered to introduce minimum energy performance standards as well as an energy label for these products. In other regions of the world, such requirements already exist, including countries that produce comfort fans that are destined for the European market. The MEPS in the manufacturing countries however do not guarantee high efficiency products. The paper will illustrate the environmental dumping that is taking place in Europe where the products that are being exported from the manufacturing countries often have a lower energy efficiency performance than the domestic minimum energy performance standard in place in the country of origin. It will subsequently compare the energy efficiency of the products available in Europe with the mandatory energy efficiency requirements in China. In 2015, 25 million units were sold in the European Union. In 2020, this number increased to 52 million units. With rising temperatures, this number will continue to grow. An efficient comfort fan can also be an alternative solution to installing an air conditioner, thus achieving additional energy savings.

Keywords: air flow, product import, MEPS; energy efficiency requirements, dumping, best available technologies.

Introduction

This paper will investigate the case of environmental dumping in terms of energy efficiency of comfort fans that is taking place within the European Union. This refers to products that do not respect the domestic minimum energy performance standards (MEPS) in their country of origin but are exported to the European market where no energy efficiency requirements exist. The paper will show that existing MEPS in the country of origin are not sufficient to guarantee that a minimum energy efficiency standard is applied to exports.

The paper will also show that many countries already have requirements in place, which would make barriers and efforts for the European Union to adapt or harmonize their own requirements very low. The existing information requirements that are required in the Commission Regulation (EU) No 206/2012 for air conditioners and comfort fans are insufficient and are not being applied. Based on a market assessment performed by Topten in 2018, a significant share of models does not comply with the Chinese MEPS, which is where a greater part of comfort fans is imported from.

The expected energy savings from comfort fans was estimated at 1 TWh, however good and efficient comfort fans are in many cases a viable alternative to air conditioners. The energy savings from an increased use of comfort fans instead of new air conditioners are much more significant.

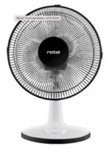
Topten, the author of this paper, is an independent platform that presents the most energy efficient products on the market for household and commercial use. To be listed, products need to fulfill the selection criteria defined by Topten. They are based on existing standards and regulations and consider the product's energy efficiency and environmental impact, resource efficiency and health impacts. The platform is used by policymakers as a source of data and science-based recommendations to develop new regulation.

Terminology

Comfort fans

According to the European Ecodesign Commission Regulation (EU) No 206/2012 for air conditioners and comfort fans, a comfort fan is an "appliance primarily designed for creating air movement around or on part of a human body for personal cooling comfort, including comfort fans that can perform additional functionalities such as lighting"[11]. Fans can be further classified as table fans, floor standing fans, pedestal fans, wall-mounted fans, tower fans and ceiling fans.

Table 1. Construction types of comfort fans according to the definitions in the Ecodesign preparatory study for comfort fans [9]



Source: Rotel

Table fan
Table fans are suitable for individuals but cannot ventilate larger rooms. Table fans are usually not height-adjustable, so the user needs to improvise to set the right height.

Source: Sonnenkoenig

Floor standing fan
Floor standing fans - sometimes also called air circulators - provide an intensive circulation of air in a room. They should not be directed against a person because of their strong airflow.

Source: Solis

Pedestal fan
Pedestal fans are ideal for larger rooms, as they are often height-adjustable and rotatable and can therefore reach the whole space.

Source: Satrap

Tower fan
Tower fans produce a lower airflow and are less energy-efficient than floor fans, but the airflow produced is evenly distributed and can feel more pleasant to the user. The rotor blades are not visible from the outside, which can give a feeling of higher safety to certain people.

Source: CasaFan

Ceiling fan
Due to the large rotor blades, they are very efficient and quiet. Some models have integrated lamps. Ceiling fans must be installed fixedly.

Today many hybrid fans are appearing on the market such as fans with air filtration systems, humidifying or heating functions. These products are situated in a higher price segment. This paper covers simple comfort fans. The energy efficiency of the fan for hybrid fans can still be assessed if the hybrid functions can be disabled during the product testing.

Environmental dumping

Environmentally harmful product dumping (hereinafter referred to as "environmental dumping") is a practice historically associated with the export of hazardous product waste and associated unwanted chemicals from a developed country for irresponsible and often illegal disposal in a developing country [1]. Anderson et al. (2018) expanded the definition which now also refers to the practice of exporting products or technologies that cannot be legally sold in the country of origin because of environmental, safety, energy efficiency or any other product standards to another country or territory with less stringent or non-existent regulations. This practice undermines the ability of the importing country to fulfil their environmental objectives and is contrary to the interest of consumers.

Energy efficiency measurement method

The performance and energy consumption of comfort fans is measured with the International Electrotechnical Commission (IEC) standard 60879:2019 "Performance and construction of electric circulating fans and regulators". The standard "specifies the performance-measuring methods of comfort fans and regulators for household and similar purposes, including conventional fans, tower fans and bladeless fans, their rated voltage being not more than 250 V for single-phase fans and 480 V for other fans, and their rated power input being less than 125 W" [19]. The standard also includes functional requirements as well as recommended design values in terms of preferred sizes that lead to the common declared characteristics of products that are observed on the market. The fan "Service Value" is a metric used across many countries or regions such as China or Malaysia. Most countries using the Service Value as the main metric also have measurement standards that are based on IEC 60879:2019 [7]. It is the main metric to calculate the energy efficiency of comfort fans and is expressed in m^3/min/W. It is a ratio of the flow generated to the electrical power absorbed and is measured at maximum speed. The flow is measured without any oscillation function of the fan. When this metric is used as a criterion for the minimum requirements, manufacturers are incentivized to optimize the motor efficiency and the overall design of the device including the blades to displace a maximum amount of air per Watt.

$$Service\ Value = \frac{\frac{m^3}{min}}{W}$$

Well-designed blades will displace more air per minute (high m^3/min) and an efficient motor will require a low power input to rotate at full capacity (low power input, W). A comfort fan can reach a high Service Value by increasing the airflow, decreasing the power input or by doing both.

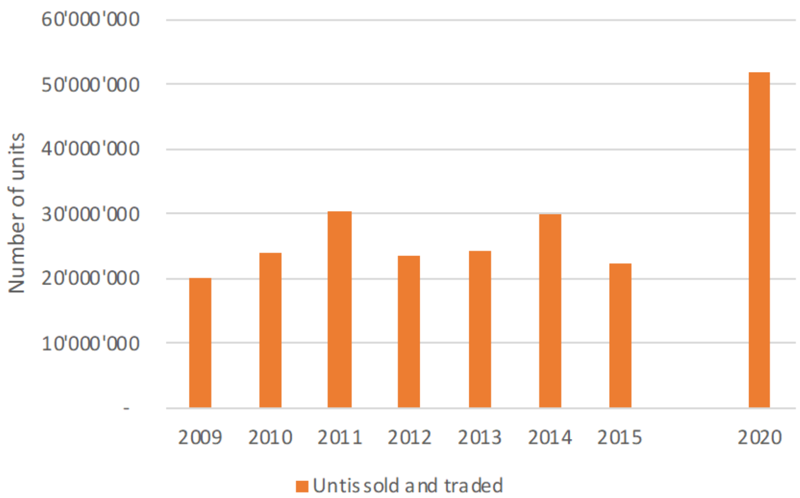
Ceiling fans are in general subject to higher requirements than other types of fans because of their larger blade sweep and their ability to displace more air.

European market for comfort fans

The EU Ecodesign preparatory study for air conditioners and comfort fans [9] estimated that the annual sales of comfort fans in the EU increased from 10 to 25 million units from 2000 to 2005 with a peak in sales in 2004 with 35 million units, because of a strong heat wave in that year. Sales are strongly correlated with the weather, which means that they are expected to grow as summers get warmer as consequence of climate change. This can also be confirmed for example by the supply shortages faced by retailers in recent years in France, Germany, and the United Kingdom ([17],[4],[20]) in the first half of the year. Since then, heat waves have been regularly occurring in the summer throughout Europe.

In the EU Ecodesign review study [13], the sales and trades of comfort fans in the EU countries were estimated to be in between 20 and 30 million units per year for the period between 2009 and 2015. The study further assumes that sales of comfort fans will progressively decline due to the competition with air conditioners (17 million units sold in 2025). This assumption has proven to be incorrect so far, as shown by recent UN Comtrade data showing that imports of fans in the EU-28 actually have doubled, reporting an import of 52 million units in 2020.

Figure 1. Total units of comfort fans below 125 W sold and traded in the EU from 2009 to 2015 and 2020. ([13],[26]).



The sales data shows that the estimates from the preparatory study underestimated the market for comfort fans, given that they are for consumers a quick and cheap solution in cases of extreme heat waves.

European regulatory framework for comfort fans

In the EU, the Ecodesign Commission Regulation (EU) No 206/2012 defines product information requirements for air conditioner and comfort fans. However, the regulation does not set any further requirements such as noise limits or MEPS for them. The review study for the air conditioners and comfort fans regulation [13] mentions that due to a lack of data on comfort fans (i.e., data on product efficiency, energy consumption) in the EU at the time of policy design for Commission Regulation (EU) No 206/2012, the European Commission introduced just product information requirements to begin a systematic product data gathering process. The data from these information requirements was supposed to be monitored and collected by market surveillance authorities and to be used for setting future minimum energy efficiency requirements when a review of the regulation takes place.

Table 15. Information requirements for comfort fans in Commission Regulation (EU) No 206/2012

Information to identify the model(s) to which the information relates to			
Description	**Symbol**	**Value**	**Unit**
Maximum fan flow rate	F	[x,x]	m^3/min
Fan power input	P	[x,x]	W
Service Value	SV	[x,x]	(m^3/min)/W
Standby power consumption	PSB	[x,x]	W
Fan sound power level	LWA	[x,x]	dB(A)
Maximum air velocity	C	[x,x]	meters/sec
Measurement standard for service value	[State here the reference to measurement standard used]		
Contact details for obtaining more information	Name and address of the manufacturer or of its authorized representative		

The Ecodesign regulation for air conditioners and comfort fans is currently being reviewed, but the review study [13] brought only very little new knowledge on this product category. It discusses comfort fans only very briefly, refers mostly to the 2008 Preparatory Study and explains that due to a persistent lack of data concerning the comfort fan products on the market, it cannot draw any further conclusions. In comparison to air conditioners (the other product category covered by Commission Regulation (EU) No 206/2012) comfort fans appear to be less complex and might represent a comparatively smaller energy savings potential. Because of a lack of information, after the request from stakeholders, the European Commission published an Addendum Report for comfort fans [15]. The most recent draft regulation [14] contains at least a proposal for MEPS for comfort fans (Table 2), which follows the same approach as the Chinese MEPS. Accordingly, MEPS are based on the Service Value and differ according to the size of blade sweep (Table 3).

Table 16. Proposed MEPS for comfort fans in the EU draft regulation for ACs and comfort fans [14]

Comfort Fan categories	**SV (m^3/min)/W**
All comfort fans, except ceiling fans, with a fan diameter ≥ 20 and < 25 cm	0.5
All comfort fans, except ceiling fans, with a fan diameter ≥ 25 and < 30 cm	0.65
All comfort fans, except ceiling fans, with a fan diameter ≥ 30 and < 40 cm	0.75
All comfort fans, except ceiling fans, with a fan diameter ≥ 40 and < 50 cm	1.08
All comfort fans, except ceiling fans, with a fan diameter ≥ 50 and < 60 cm	1
All comfort fans, except ceiling fans, with a fan diameter ≥ 60 cm	1.1
Ceiling fans, with a fan diameter > 0 and < 60 cm (23”)	1.4
Ceiling fans, with a fan diameter > 60 and < 90 cm (35”)	2.6
Ceiling fans, with a fan diameter ≥ 90 and < 120 cm	3.1
Ceiling fans, with a fan diameter ≥ 120 and < 140 cm	4.0
Ceiling fans, with a fan diameter ≥ 140 and < 150 cm	4.1
Ceiling fans, with a fan diameter ≥ 150 cm	4.3

Minimum requirements for tower fans were not included in the draft regulation because the review study concluded that the IEC 60879:1986 standard still valid at that time did not include a measurement method for tower fans. This is however not correct anymore, as the new 2019 version of the standard (published after the end of the review study) added a measurement method also for tower fans and bladeless fans. Indeed, the whole review study, impact assessment and recommendations for policy design used for the still on-going revision process are essentially based on a previous and out-dated version of the IEC standard and not the newly published version, which was already under preparation at that time.

Energy efficiency requirement for comfort fans in Asia

Overall, several countries in Asia already have regulations in place that set minimum energy efficiency requirements for comfort fans. Indonesia is in the process of setting MEPS for these products as well [7].

China

In China, the regulation GB 12021.9 (2008) for comfort fans sets MEPS and includes an energy labelling scheme for these products. The metric used is the Service Value and the national measurement standard is based on the IEC 60879 (year unknown). The MEPS level is set at the energy efficiency grade three.

Table 17. China's energy efficiency grades for electric fans expressed in m3/min/W [5].

Type		**Specifications (mm)**	**Energy efficiency value**		
			Energy efficiency grade		
			1	**2**	**3 (= MEPS Level)**
Table fans, rotary fans, wall fans, box fans, stand fans	Capacitive	200	0.71	0.60	0.54
	Shaded pole		0.63	0.51	0.45
	Capacitive	230	0.84	0.70	0.64
	Shaded pole		0.65	0.57	0.50
	Capacitive	250	0.91	0.79	0.74
	Shaded pole		0.72	0.61	0.54
	Capacitive	300	0.98	0.86	0.80
		350	1.08	0.95	0.90
		400	1.25	1.06	1.00
		450	1.42	1.19	1.10
		500	1.45	1.25	1.13
		600	1.65	1.43	1.30
Ceiling Fans	Capacitive	900	2.95	2.87	2.75
		1050	3.10	2.93	2.79
		1200	3.22	3.08	2.93
		1400	3.45	3.32	3.15
		1500	3.68	3.52	3.33

The regulation also sets noise limit requirements according to the type of fans and the size of the blades.

The standard was revised in 2021 and the new version will be implemented in November 2022. In this new version additional requirements were made on standby consumption and the MEPS were significantly increased for all product types [21]. The proposed MEPS from the European Commission are much weaker than the new MEPS that have been adopted by China. The proposal from the Commission should therefore be reconsidered and aligned with the new Chinese standard.

Type	**Size (mm)**	**Energy efficiency value**		
		Energy efficiency grade		
		1	**2**	**3 (= MEPS Level)**
Table fans, rotary fans, wall fans, box fans, stand fans	200	1.00	0.70	0.45
	200 < X ≤ 230	1.10	0.84	0.55
	230 < X ≤ 250	1.30	0.95	0.65
	250 < X ≤ 300	1.50	1.05	0.78
	300 < X ≤ 350	1.65	1.15	0.93
	350 < X ≤ 400	1.85	1.35	1.03
	400 < X ≤ 450	2.15	1.50	1.15
	450 < X ≤ 500	2.40	1.55	1.20
	500 < X ≤ 600	2.65	1.70	1.37

Ceiling Fans	900	3.95	2.95	2.75
	900 < X ≤ 1050	4.40	3.10	2.79
	1050 < X ≤ 1200	4.52	3.22	2.93
	1200 < X ≤ 1400	4.75	3.45	3.15
	1400 < X ≤ 1500	4.98	3.68	3.33
	1500 < X ≤ 1800	5.11	3.81	3.47

The table below compares the MEPS for comfort fans of the EU proposal [15] with the MEPS of the Chinese MEPS from 2008 and 2022 ([21], [22]). The highlighted cells show the most ambitious MEPS levels. With the new Chinese MEPS, the requirements for all fans will be more stringent than the European proposal except for very small fans and ceiling fans.

Table 18. Comparison of draft European regulation MEPS and Chinese MEPS from 2008 and 2022 ([15], [21], [22])

Type	**Size (mm)**	**EU Proposal**	**China (2008)**	**China (2022)**
Table fans Rotary fans Wall fans Box fans Stand fans	200	0.5	0.45	0.45
	200 < X ≤ 230	0.5	0.45	0.55
	230 < X ≤ 250	0.5	0.5	0.65
	250 < X ≤ 300	0.65	0.54	0.78
	300 < X ≤ 350	0.75	0.8	0.93
	350 < X ≤ 400	0.75	0.9	1.03
	400 < X ≤ 450	1.08	1.00	1.15
	450 < X ≤ 500	1.08	1.10	1.20
	500 < X ≤ 600	1	1.13	1.37
Ceiling Fans	900	3.1	2.75	2.75
	900 < X ≤ 1050	3.1	2.75	2.79
	1050 < X ≤ 1200	3.1	2.79	2.93
	1200 < X ≤ 1400	4.0	2.93	3.15
	1400 < X ≤ 1500	4.1	3.15	3.33
	1500 < X ≤ 1800	4.3	3.33	3.47

India BEE voluntary labelling scheme for ceiling fans

The India Bureau of Energy Efficiency (BEE) initially set up a voluntary labelling scheme for ceiling fans. The scheme was supposed to become mandatory in July 2020 [6], however, it has been postponed due to the Coronavirus pandemic. It is now expected to come into force in July 2022 [21].

The star rating plan for ceiling fans is shown in Table 5,

Table 19. Star Rating Index Calculation for Ceiling Fans [3]

Star Rating	**Service Value for Ceiling Fans for sweep size < 1200 mm (i.e., 900 mm and 1050 mm)**	**Service Value for Ceiling Fans for sweep size ≥ 1200 mm (i.e., 1200 mm, 1400 mm, and 1500 mm)**
1 Star	≥ 3.2 to < 3.4	≥ 4.0 to < 4.5

2 Star	≥ 3.4 to < 3.6	≥ 4.5 to < 5.0
3 Star	≥ 3.6 to < 3.8	≥ 5.0 to < 5.5
4 Star	≥ 3.8 to < 4.0	≥ 5.5 to < 6.0
5 Star	≥ 4.0	≥ 6.0

Malaysia

The requirements for comfort fans are also based on the Service Value although the regulation uses the term "Coefficient of performance (COP)". The regulation uses a star rating for the different classes of energy efficiency [8]. The MEPS are currently set at the 2-star level (Table 6).

Table 20. Malaysia's star rating for electric fans (Attorney General's Chambers of Malaysia, 2013)

Star rating	**Ceiling fan**	**Pedestal, wall, and desk fan**
	Minimum COP	**Minimum COP**
5	≥ 3.00	≥ 1.20
4	2.74 – 2.99	1.12 – 1.19
3	2.66 – 2.73	1.08 – 1.11
2 (MEPS)	2.58 – 2.65	1.01 – 1.07
1	2.50 – 2.57	0.93 – 1.00

Vietnam

In Vietnam the MEPS are also based on the Service Value and are set according to the blade sweep (D) [24]. The Service Value is measured according to a standard that is equivalent to IEC 60879 [7]. In the labelling scheme there are five energy efficiency levels (R), which are determined by the ratio of the measured energy efficiency to the minimum energy performance standard (Table 7 and Table 8).

Table 21. Minimum energy efficiency for table vertical and wall fans in Vietnam [24]

Blade sweep (mm)	**MEPS (m^3/min/W)**
D < 230	0.54
230 ≤ D < 250	0.64
250 ≤ D < 300	0.74
300 ≤ D < 350	0.80
350 ≤ D < 400	0.90
400 ≤ D < 450	1.00
450 ≤ D < 500	1.10
500 ≤ D < 600	1.13
D ≥ 600	1.30

Table 22. Minimum energy efficiency for ceiling fans in Vietnam [24]

Blade sweep (mm)	**MEPS (m^3/min/W)**
D < 900	2.75
900 ≤ D < 1050	2.79
1050 ≤ D < 1200	2.93
1200 ≤ D < 1350	3.04
D ≥ 1350	3.15

Market-based data analysis

In 2018, Topten performed an assessment of the comfort fans sold in Switzerland with the intention of creating a product list with the most efficient products. All requirements of Commission Regulation (EU) No 206/2012 were adopted in Switzerland as well. The information requirements for comfort fans are identical and also mandatory in Switzerland. Topten product lists in general select the most efficient products on the market. The steps taken to initially create a product list are the same for all product categories. Topten first creates an overview of the products available on the market, and based on that data, determines selection criteria to select the best performing units.

Topten collected the product information for comfort fans on the websites of approximatively 39 manufacturers and 6 retailers. Most of the assessed manufacturers are also present in the European Union. When a product did not display the information required by the information requirements of Commission

Regulation (EU) No 206/2012 or the information needed to calculate the Service Value, Topten first downloaded the product information sheets and user manuals to verify if the information was present in these documents. When the information was still missing, Topten directly contacted the manufacturers and importers asking them for the data (for data information requirements see Table 1). In many cases, Topten had to explain what was the information that was being requested as the manufacturers or importers were unaware that such requirements existed or what the data was.

Results

In the market overview, Topten evaluated 158 models of comfort fans that were on sale in Switzerland in 2018. Out of these 158 models, only eight declared all the information that is required by Commission Regulation (EU) No 206/2012. From the manufacturers, Topten received enough data to assess or calculate the Service Value of 67 models. In total - together with own research - it could assess the performance of 75 models (Table 9).

It is not clear why the product data for these products is so scarce. Some manufacturers did not even know that these requirements existed. To assess whether this was only an issue in the Swiss market, surveys on websites of other European retailers and the European websites of manufacturers showed that this lack of product declaration existed in other countries. Market surveillance authorities are responsible for the correct product declaration, and it is likely that since these products are not subject to any MEPS, they do not list high on their priority list, leaving no enforcement of the regulation to take place.

Table 23. Assessment of comfort fans for a Topten product list (data gathered by Topten, 2018)

Number of models evaluated	158
Number of models that fulfill the product information requirements of Commission Regulation (EU) No 206/2012	8
Number of models for which data was received after contacting the manufacturer	67
Total number of models with complete product information, complemented by own research	75

This paper shows that the information requirements are rarely respected. The product survey showed that in most cases (89% of all products), products do not comply with the regulation already in force (i.e., the product information requirements). The information requirements were set in 2011 to gather data for the review of Commission Regulation (EU) No 206/2012. However, the situation with a persistent lack of data is jeopardizing the introduction of MEPS for comfort fans also in the current revision process of Commission Regulation (EU) No 206/2012, because not much more official data on product performance is available today.

The data shows that there is no clear correlation between the “fan input power” and the “maximum airflow”. As expected, the average maximum airflow of some fan types is higher than others. The design of the blades and their size play a substantial role in the effectiveness of the fans. The “Service Value” takes both aspects into account.

Figure 37. Distribution of floor standing comfort fans according to maximum airflow [m^3/min] and fan power input [W] (data gathered by Topten, 2018)

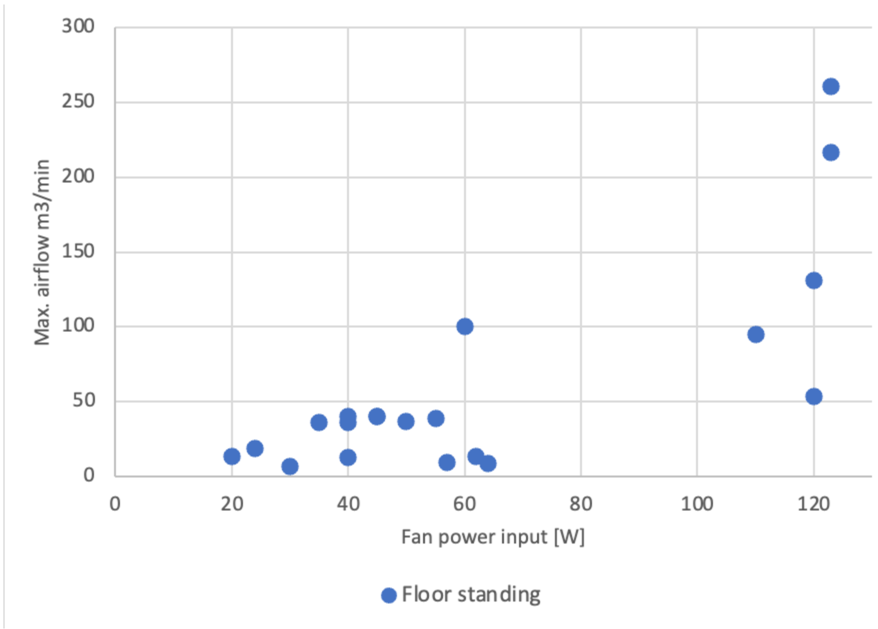


Figure 38. Distribution of ceiling comfort fans according to maximum airflow [m^3/min] and fan power input [W] (data gathered by Topten, 2018)

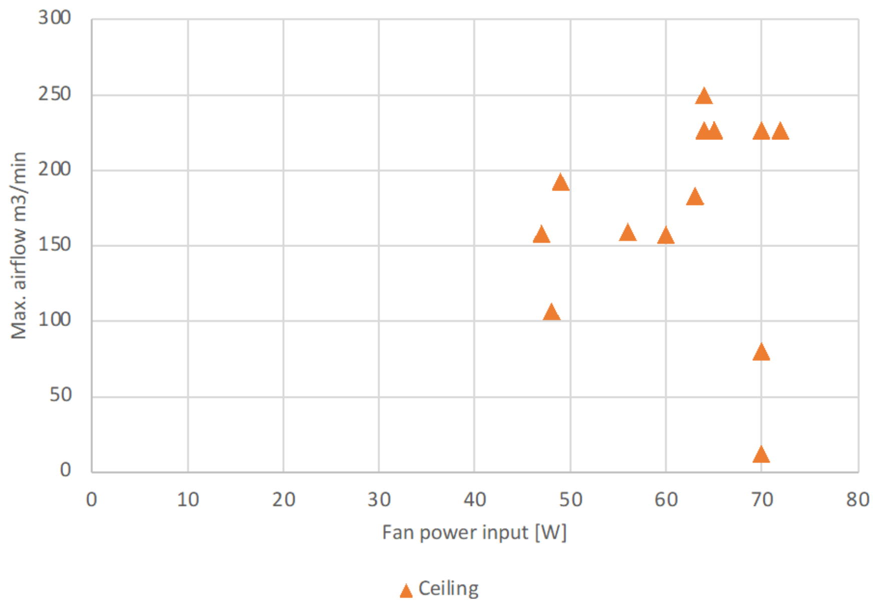


Figure 39. Distribution of pedestal comfort fans according to maximum airflow [m³/min] and fan power input [W] (data gathered by Topten, 2018)

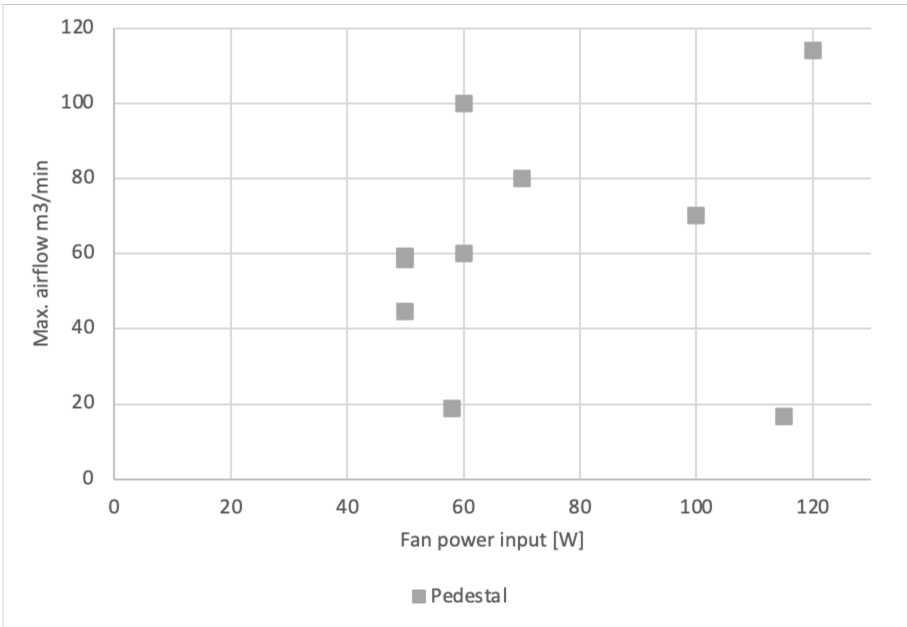


Figure 40. Distribution of table comfort fans according to maximum airflow [m³/min] and fan power input [W] (data gathered by Topten, 2018)

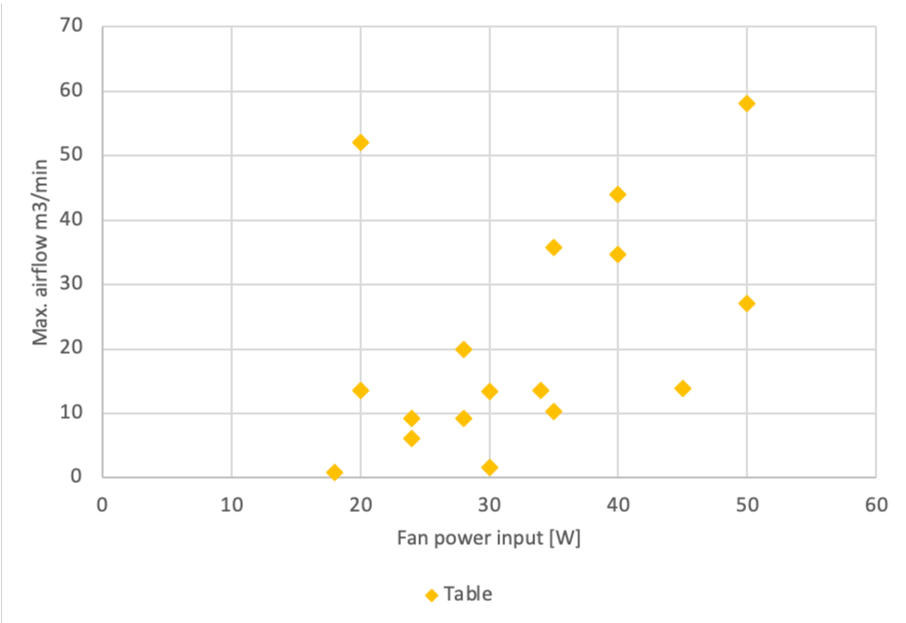
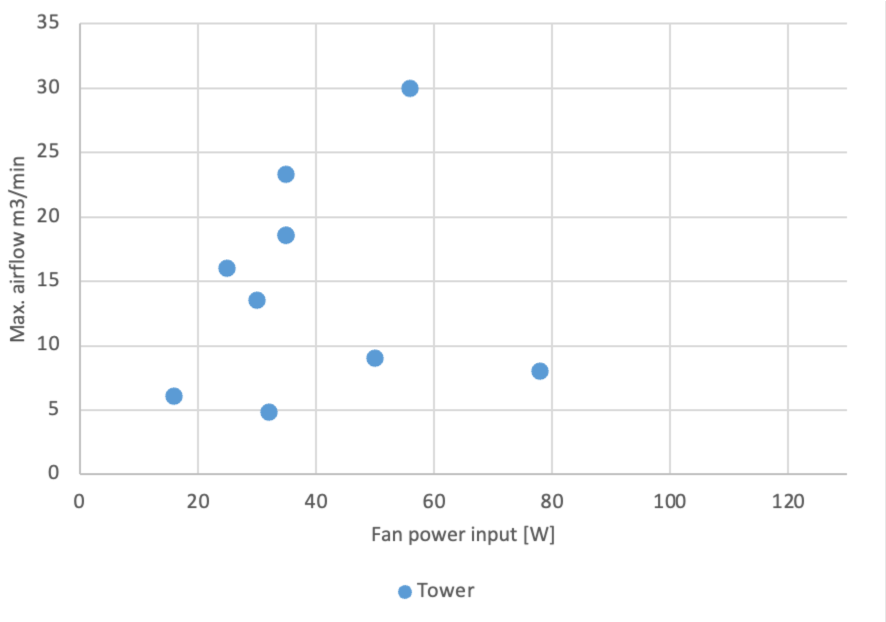


Figure 41. Distribution of tower comfort fans according to maximum airflow [m³/min] and fan power input [W] (data gathered by Topten, 2018)

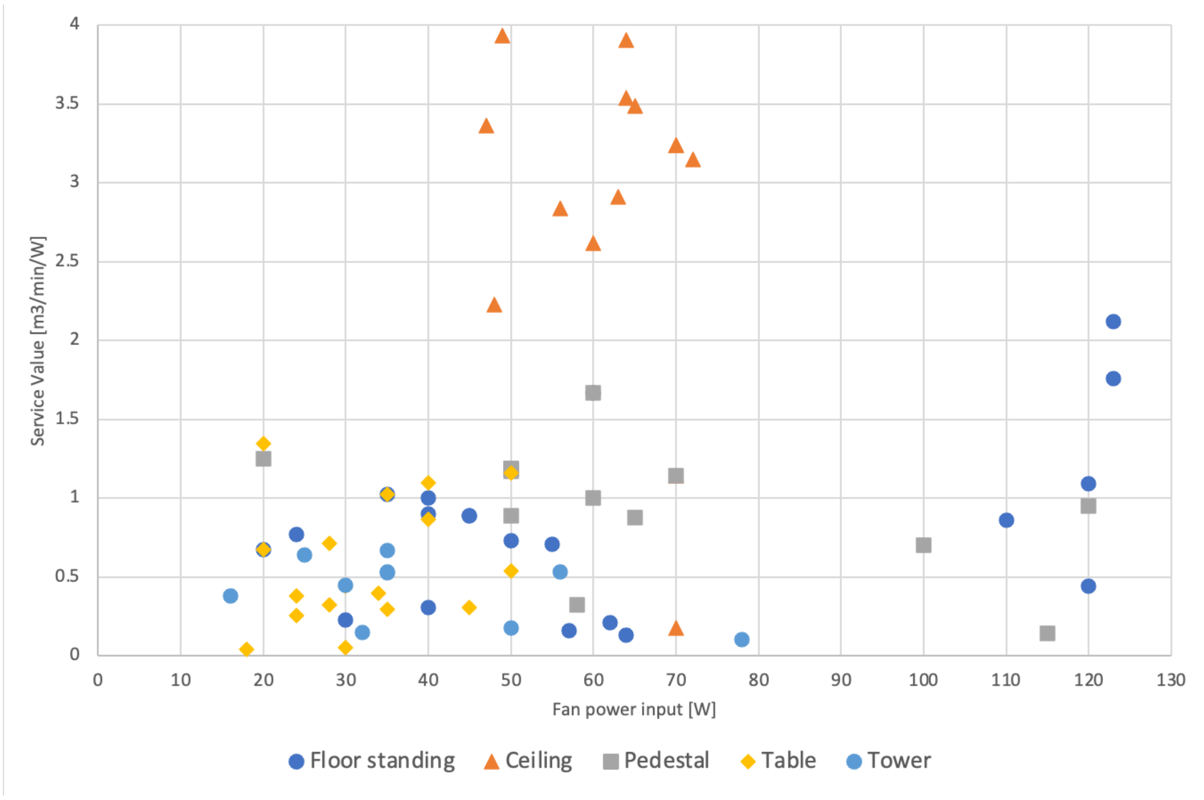


Topten criteria definition for comfort fans

Based on the available data from the 75 models, Topten empirically determined the selection criteria for each fan construction type. Using the Service Value as the parameter for the selection criteria (Figure 6), it defined a threshold that would select the top 50% of available models for the product list (Table 10)[272]. The criteria could not be too stringent for this specific product group, because the product list would otherwise only contain a few models and would not be useful to the consumer. Also, as a rule for Topten, the selection criteria must be straightforward and easy for consumers to understand. Therefore, for these two reasons, Topten also did not use the Chinese MEPS as references (where the Service Value threshold depends on the size of the blade sweep), because there would be 1) too few products on the list and 2) the criteria would be too complicated to understand for consumer. It therefore opted for one Service Value threshold for each construction type.

[272] Topten product lists usually select the top 20% -30% performing products available on the market. In some cases, when the product is an alternative for another product (group) that consumes more energy, the selection criteria are more lenient. In this case comfort fans are an alternative to air conditioners (especially portable units), which consume much more electricity. Therefore, the selection criteria are more lenient and encompass 50% of the existing market.

Figure 42. Distribution of fans (according to construction types) in relation to the Service Value. The Topten selection criteria were based on the service value and selected the 50% best performing products (data gathered by Topten, 2018).



As the Topten product list went online for the first time in May 2018, it contained 41 models of comfort fans. In the subsequent years, manufacturers announced new products and the list could grow. As of May 2022, 120 models are listed on Topten. The Topten selection criteria were also strengthened in 2021 for table and floor standing fans as the number of efficient models grew (Table 10).

Table 24. Topten selection criteria for comfort fans [25]

Construction type	**Topten selection criteria (2018) Service value (m^3/min/W)**	**Revised selection criteria (2021) Service value (m^3/min/W)**
Pedestal	≥ 1.00	≥ 1.00
Ceiling	≥ 2.75	≥ 2.75
Table	≥ 0.50	**≥ 0.80**
Floor standing	≥ 0.75	**≥ 0.80**
Tower	≥ 0.45	≥ 0.45

Comparison of comfort fans on the European market with the Chinese MEPS

Most comfort fans being imported into the European Union are produced in China. According to UN Comtrade (2020), this amounts to 95% of units by volume or 90% by value. For this reason, the energy efficiency of the models that were part of the market assessment in 2018 (data on all products on the market) and the energy efficiency of the products of the Topten list in 2021 (best performing products of the market) were compared to the MEPS that were into force in China in 2018 and that are still in force in 2022.

Comparison with the 2018 sample

A great part of the imported comfort fans is inefficient. Out of the 75 models with complete product data, 32 models did not comply with the Chinese MEPS (Figure 7 to Figure 9). It can be expected that the performance of the remaining models with no product declaration is also low as there is often a reporting bias as good performers tend to report more frequently than bad performers. The share of models from the market assessment that did not fulfil the Chinese MEPS in 2018 (42%) shows the extent of the potential environmental dumping in the European market.

Figure 43. Comparison of table, floor, and pedestal comfort fans with the Chinese MEPS (data gathered by Topten, 2018).

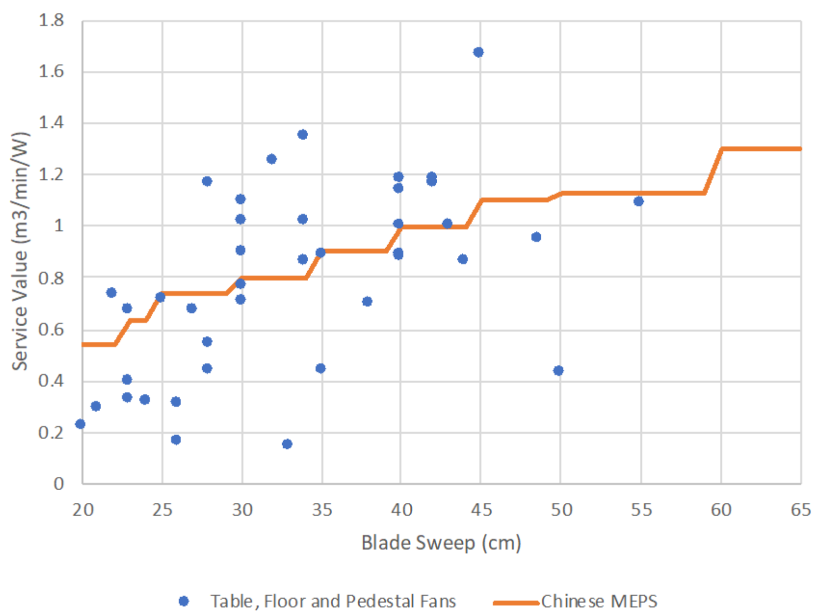


Figure 44. Comparison tower comfort fans with the Chinese MEPS (data gathered by Topten, 2018).

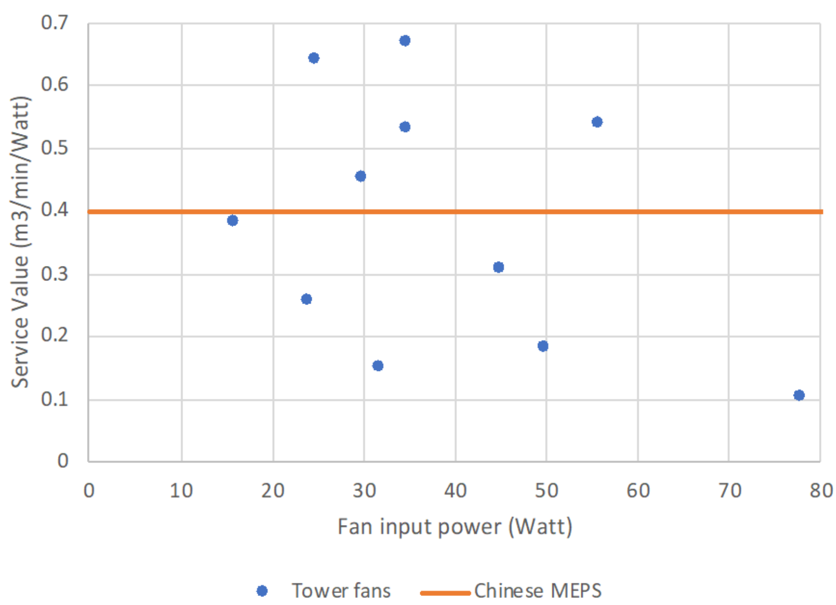
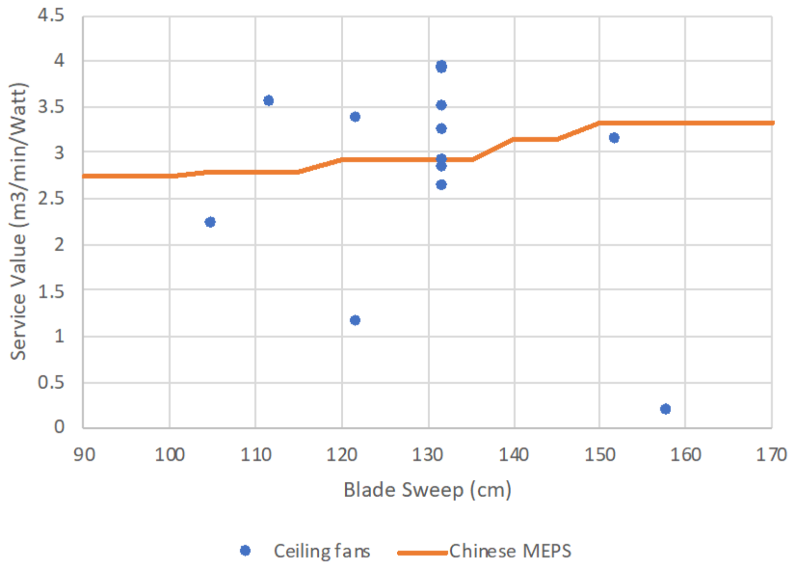


Figure 45. Comparison of ceiling comfort fans with the Chinese MEPS (data gathered by Topten, 2018).



Comparison with Topten product list (2021)

A similar comparison was made with the models that are listed on the Topten product list for comfort fans in Switzerland (2021). As a reminder, a Topten product list shows the most efficient products that are currently available on the domestic market. The selection criteria are determined empirically by selecting the top performing products on the market. The 2021 sample does not look at the overall market as it was the case in 2018. The aim was to assess whether there were improvements made among the top performing products on the market.

The 119 models listed on Topten in December 2021 were the models that fulfilled Topten's selection criteria and can be considered as the top performing models available on the market at that time. Since setting the initial selection criteria in 2018, the 2021 Topten list focuses on the current best performing products and does not consider all the products on the market that do not fulfil these criteria. It is therefore likely that the 2021 Topten product list does not exactly correspond anymore to the top 50% performing products on the market, but a much more comprehensive new market analysis would be needed to assess this aspect more in detail.

Nevertheless, the findings for 2021 are very clear. Out of the 119 products listed in 2021, 12 Topten products did not comply with the MEPS that are currently still into force in China. Among these are three floor standing fans, six ceiling fans, two pedestal fans and one table fan. Furthermore, three additional models did not comply with the Chinese noise limits. This means that some of the best models in Europe do not comply with the Chinese MEPS.

Table 25. Number of products on Topten that did not fulfill the requirements of the Chinese MEPS (Topten data, 2021)

	2018	**2021**
Topten products that do not comply with the Chinese MEPS	10 models (24%)	12 models (9%)

A smaller proportion of models do not fulfil the requirements of the Chinese MEPS because Topten could strengthen the selection criteria for two fan construction types (Table 10). The increase in the size of the Topten product list is a positive sign that manufacturers also started paying more attention to the information requirements and started reporting the data requested by Commission Regulation (EU) No 206/2012.

If even some Topten eligible models do not comply with the Chinese MEPS, this means that many of the comfort fans that do not fulfil the Topten selection criteria, most likely don't fulfil the Chinese MEPS as well.

Conclusion

The analysis of the data gathered by Topten showed that many comfort fans that are being imported to Europe are inefficient. Products that are not allowed to be sold domestically in the country of origin (i.e., China) are still being manufactured with the intention of exporting them to countries or regions with lower or no requirements in terms of energy efficiency. This practice is a case of environmental dumping and although it is legal, it is clearly against the interests of the customers in the importing countries, which are often not aware that they are receiving low quality products that even the exporting country does not want to use for its own market. Although the current Ecodesign review study uses a statement from the 2012 Impact assessment stating that *"setting efficiency requirements at similar level as in China/Taiwan with risk of removing virtually all comfort fans from the EU market"* ([12]. p. 29), this argument is definitively not valid anymore, as Topten shows that there are already in 2021 manyavailable efficient products. To mitigate this situation, it is important for the importing countries or importing regions (i.e., the European Union) to set their own requirements that are more stringent than the requirements of the exporting country or at least to harmonize them with the ones of the country of manufacturing. As it stands today, even if the European proposal is adopted, environmental dumping will still be occurring. The requirements in China have been into force since 2008, obviously without hampering the market of efficient and affordable comfort fans there. With the new standard coming into force (2022), the same minimum performance requirements in Europe should be implemented and should be quite simple as the groundwork has already been laid for policy and technology. Without doubt, this will in return also provide the European consumers (and potentially also other world-regions) with better and more efficient products that improve their quality of life. Indeed, a consumer might need to buy several inefficient fans to achieve the same results that an efficient fan would yield for less money and energy.

Another concern are the exceedingly high MEPS levels for ceiling fans in the European proposal. For example, these MEPS are higher than the Topten criteria, which is a service value of 2.75. These products are still not very common in Europe, but they provide a very nice cooling effect and could be very effective in replacing and avoiding the new installation of air conditioners. These extremely high MEPS could make it much more difficult for these products to take off.

On the side of European policymaking, the current process of joint regulation for air conditioners and comforts fans clearly acts in disfavour of comfort fans, as all the attention in the review process is being focused on air conditioners. In fact, comfort fans are barely mentioned throughout the whole process. The recommendations on policy design for fans are placed in an annex and are - even worse - based on a previous and out-dated version of the applicable IEC standard (stemming from decades ago). One of the main justifications given by the EU review study for the lack of new information throughout the document is the supposedly missing product data on the energy efficiency of the comfort fans on the market, despite the (obviously not enforced) EU product information requirements being into force for many years. On the other hand, comfort fans alone with approximately 50 million units sold in 2020 already exceed by far the threshold defined in the Ecodesign Directive [10] of more than 200,000 units sold per year to be covered by an implementing measure. Multifunctional products should not be a reason to avoid regulating comfort fans. Ecodesign has already tackled other products that are even more complex and therefore should be able to find a solution to tackle these products. Other countries that already have regulations in place also have multifunctional products on their markets.

Additionally, for the second requirement of the Ecodesign Directive on the significant saving potential, the addendum report expects the energy savings to be in between 1 and 2 TWh by 2030 if at least the same MEPS as the ones in place in China and Taiwan were introduced [15]. The current review study still uses the same assumptions on energy savings, which are most likely much too low considering that actual sales have increased dramatically and clearly do not reflect the assumptions of the review study. Accordingly, the actual energy saving potential is expected to be even higher and therefore also fulfil the second criteria of the Ecodesign Directive on significant saving potential in the European Union in any case. Moreover, efficient and effective fans serve as an viable alternative to air conditioners in certain conditions. The use of fans could curb the increase of air conditioners and therefore lead to an overall energy saving.

Therefore, the EU should definitely implement at least the same minimum performance requirements as in the main exporting countries of comfort fans (i.e. China) or, even better, own EU requirements that are more stringent to use the full saving potential of the many efficient products already available on the market (as shown by the Topten product list). Based on this Topten study, it is also urgently recommended to the European Commission to include MEPS also for tower fans and bladeless fans or to include at least a special early revision clause for these product groups, as a new IEC standard also covering these types of fans is available since 2019. Furthermore, to achieve the targets of Ecodesign more effectively, it is also recommended to the European Commission to separate the two product groups of ACs and comfort fans from one another in future preparatory and review studies.

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Strategizing energy efficiency policies based on monitoring of the market for energy efficiency services

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Abstract

In collaboration with scientific partners, the German Federal Energy Efficiency Center (BfEE) monitors the market for energy efficiency services in Germany. To this end, the consortium undertakes comprehensive surveys and prepares a market study annually since 2016. The study shows the current state and development of the market, it also discusses possible ways of enhancing it. Further, the study offers insights on the impact of the current policy framework and conceivable improvements.

The market study examines issues such as consumer behaviour, energy demand, applied energy efficiency technologies and used subsidies. Besides, it examines the role of energy efficiency for three main customer sectors- private households, commercial sector, and industry as well as public properties. In total, 3000 households, including tenants and property owners, over 2700 private enterprises and more than 500 public bodies are surveyed every year. The results are enriched with qualitative data and are subject to statistical analysis.

A good understanding of the market is crucial for the development of adequate instruments in its support and for the facilitation of further investments in energy efficiency. Therefore, the market needs to be monitored regularly. In comparison to mature markets for largely standardised products, the energy services market is heterogeneous and dynamic. Additionally, there is limited data and literature available which underlines the need for regular monitoring.

Based on the results in the last 5 years of market surveillance the paper outlines possible links between the subsidies and the implementation of efficiency measures as well as different trade-offs in customer behaviour and motivations. Furthermore, it concludes how energy efficiency policy and tools should be adjusted to account for the current market situation. Thus, the paper offers insights in the impact of policy incentives, significant barriers, and suitable strategies for increasing energy efficiency in the residential sector.

Survey methodology and scope of the study

Background

A dynamic market for energy efficiency services with highly qualified providers, who promote and enable sustainable investments, is seen as a key prerequisite for achieving national and European energy efficiency goals.

These goals are mainly regulated within the framework of the Energy Efficiency Directive (EED). Here, savings targets are set for the individual member states in relation to the overall system as well as for individual areas such as buildings. Many of these targets are transposed into German law by the Energy Services Act (Energiedienstleistungsgesetz, EDL-G). In accordance with the EDL-G of 2009, the BfEE fulfils various information and reporting obligations towards the public and the European Commission. It monitors and evaluates the market for energy services, promotes measures for its further development and provides scientific advice to the Federal Government on all energy efficiency issues.

A feasibility study was conducted by the BfEE in 2013 and focused on analysing the supply side of the market (BfEE 2013). It confirmed that there already is a relatively well-developed market for energy services in Germany. However, given the breadth and variety of market actors and products, the market can be described as very heterogeneous. Also, the understanding of the product terms differs between actors, making it difficult to define the market and to draw conclusions about market performance (Flegel et al 2017).

The term energy efficiency services (EES) is used in different ways and there is no uniform definition of the different services' components. Within the framework of the BfEE's market monitoring definitions were drawn up for the examined services and products.

The European Energy Efficiency Directive (EU Directive 2012/27/EU) defines an energy service as "... the physical benefit, utility or advantage derived from a combination of energy with an energy efficient energy-efficient technology or with measures that include the necessary operational, maintenance and control activities to deliver the service, maintenance and control activities necessary to provide the service; it is provided on the basis of a contract; and it results in the contract and, under normal circumstances, has been shown to result in verifiable and measurable or estimable energy measurable or estimable energy efficiency improvements or primary energy savings." (Energy Efficiency Directive 2012).

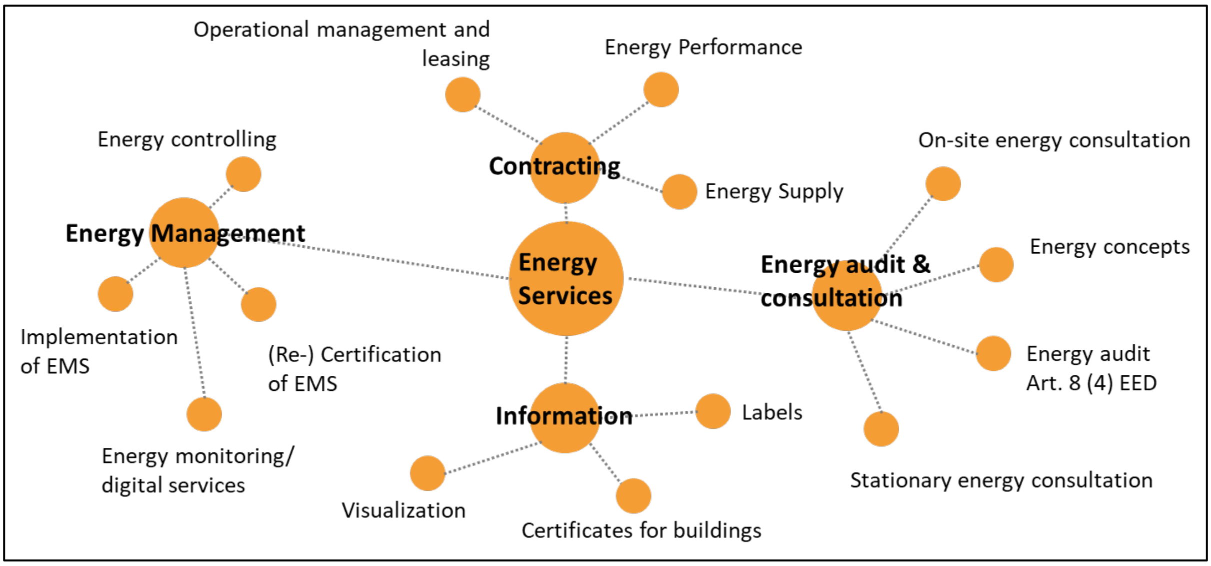
This definition is comparatively narrow, as it largely excludes e.g. consulting services and management. excluded. Many market actors, however, interpret the term energy service much more broadly. In the definition of the German Energy Services Act (EDL-G), an energy service is "any activity provided by third parties, through which the implementation of energy efficiency measures is prepared, supported, planned or carried out" (EDL-G), implementation of energy efficiency measures" (EDL-G, §2, No. 6). This study concentrates on energy service products which, due to their scope or their market due to their scope or distribution (see Figure 1).

Energy efficiency services are being defined as third-party services that aim at or include the implementation of energy efficiency measures. Professional energy service providers offer in-depth knowledge, techniques or complete solutions towards increasing energy efficiency. Energy efficiency services vary from simple online checks to complex service packages such as energy performance contracting.

For the purposes of the market study energy efficiency services were summarised in three major sub-markets of energy consulting, energy contracting, and energy management with their corresponding services as shown in Figure 1.

The EES market generates a total annual turnover of about 9 billion euros. Compared to previous surveys, the German market can thus be considered robust and stable. Still, further incentives will be needed in order to utilize the full potential of the market which has been estimated at around 34 billion euros [1].

Figure 1. Overview of the three main sub-markets with their corresponding services



Methodological approach and scope of the study

On the supply side, the market monitoring focuses primarily on energy efficiency services that tend to be offered for a fee and with a dedicated focus on increasing energy efficiency. The three major sub-sectors (Figure 1) were chosen because the corresponding services either characterize the market to a particular extent or they are of higher value in the sense of the demand for qualification of the providers. Every year around 300 suppliers are surveyed by in-depth telephone interviews and a minimum of 750 via online questionnaires. The demand side of the study is being formed by the customer groups of private households, private enterprises and public institutions. Every year approximately 2,500 private households, 2,750 private companies and more than 500 public organizations are surveyed via telephone[273]. In total every year there are at least 6,800 respondents with over 77,500 interview minutes. Therefore, the monitoring report of the BfEE is the most comprehensive analysis in the area in Germany [1].

The study encompasses many indicators which range between energy demand and consumption, usage of energy services and implementation of energy saving measures, offering prices and behavioural aspects of market actors (Table 1).

Table 1. Structure of the study: indicators, target groups and survey methods

Supply or Demand group	Service providers	Private Households	Commercial sector & industry	Public sector
Sample size & survey method	264 telephone- and 1.399 online- based interviews	2.221 telephone-based interviews with SME and 531 with Non SME	1.605 telephone-based interviews with owners and 1.013 with tenants	504 telephone- and online- based interviews
Target group	Utilities, Technology providers, Contractors, Energy auditors and consultants etc.	Owner-occupiers and rental landholders, tenants	Various branches of industry, commercial and service sectors	Federal level, state level and local authorities
Key market figures	Prices & sales Number of suppliers, regional distribution and revenue	Attitudes toward energy efficiency, implementation of measures, use of energy consultation	Usage rates of EES, prices	Internal and external use of EES,
Motivation & Outlook	Reasons for using EES Barriers to the use	Reasons and barriers for implementation of measures	Reasons and barriers for using EES	Reasons and barriers for using EES

For the purposes of improving the monitoring, modifications were made continuously over the last 5 years such as target group arrangements and share ratios as well as adjustments in the questionnaire. Target sample sizes in 2020 were therefore 1,000 tenants and 1,400 owners. An important change was the introduction of a new categorization variable for the group of the owners, which made it possible to differentiate by the use of the property and the type of ownership. This was a necessary prerequisite in order to take all the different interests into account and be able to derive specific incentive structures accordingly. As a result, three main categories were formed: landlords (rent out the property to others), owner-occupiers (use property for themselves) and owners according to the Residential Property Act (owners in commonhold associations) [1].

Private households as a market actor

In this paper, we concentrate on private households. With a 3.753.715 m^2 net heating area and 66 % share of the total energy consumption by buildings in Germany, this sector is crucial for the national energy transition

[273] Two of the public institutions were interviewed via online survey

[2]. Private households in Germany consumed more energy for housing in 2019 than in the previous year. Climate-adjusted, it was around 1.1 % more than in 2018, as reported by the Federal Statistical Office (Destatis). This continued an upward trend: while consumption fell by 14.5 % between 2000 and 2012, it has been trending upwards since then and was 10 % higher in 2019 than in 2012 [3].

The largest share of energy consumption in private households is for heating. In 2019, heating accounted for 70.7 % of total consumption. In 2019, the production of hot water accounted for 14.7 % and the operation of other household and electrical appliances for 7.8 %. The smallest shares were accounted for by process heat, i.e. the energy mainly used for cooking, and lighting, at 5.4 % and 1.4 % respectively [3].

This is particularly relevant because almost three quarters of the heating energy in German households continues to use fossil-fuels (approx. 50 % natural gas and 25 % heating oil). Renewable heating energy sources are currently still responsible for less than 10 % of decentralised heat [7].

Therefore, we are focusing on EES usage in households, motivation towards energy efficiency and in particular the implementation of measures concerning the building envelope and heating system. Our survey is designed to inform policy makers to review existing policies and introduce further instruments.

For the most part of this paper, we focus on property owners, because they genuinely have the option to implement renovation measures and more specifically on the two sub-groups of landlords and owner-occupiers, since the third category of owners in commonhold associations is relying on all the other co-owners for making any decisions regarding renovation. The group of tenants is being partially considered in the statistical analyses in this paper. The reason for this is the little scope of action for renovation tenants have. This was also reflected by the subsidy legislation which recently, as of 2021, changed and now allows tenants to apply for investment funding in the area of energy efficiency with a written consent from the owner.

In addition, behavioural changes and awareness with respect to energy use and efficiency are also increasingly evident in both groups. The current IPCC report emphasises the importance of these factors as a crucial part of the enabling conditions towards the 1.5ºC goal of the Paris Agreement and appeals to policy makers to further incentivise them [8].

In the following chapter we are offering a review of the market surveys conducted by BfEE from 2016 until 2021 concerning energy efficiency in the residential sector [1].

Key Results

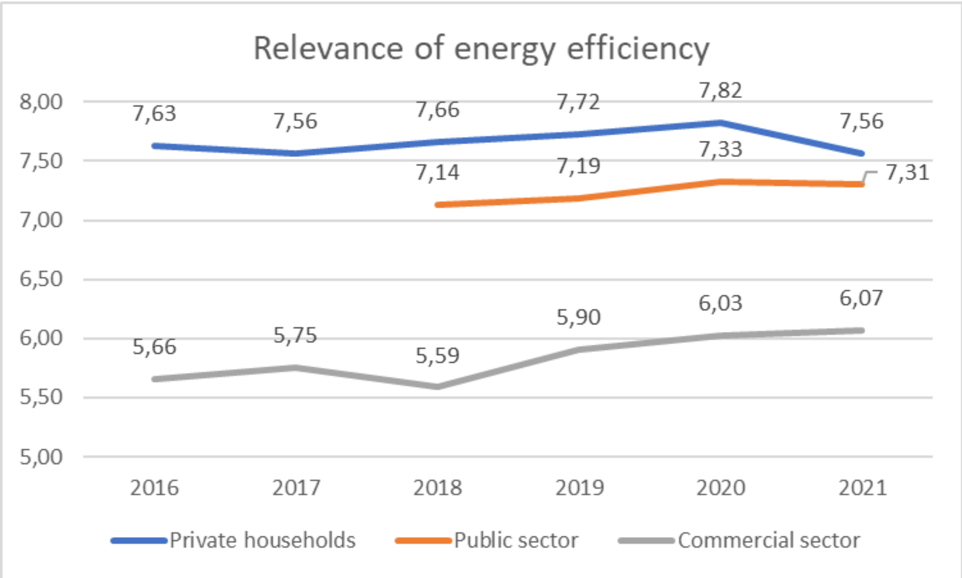
Relevance of energy efficiency for private households

A key factor for implementing energy efficiency measures and use of energy efficiency services is the relevance of the energy efficiency subject among tenants and property owners. As shown in Figure 2 private households tend to place greater importance on energy efficiency in comparison to the other two surveyed groups of private enterprises and public institutions. Even with a declining tendency (from 7.82 to 7.56 on a scale from 0 to 10) the importance placed on energy efficiency by the residential sector is still greater than by the other two groups.

The BfEE market survey reveals that energy efficiency in the view of property owners and tenants differs significantly. Possible explanations are, that tenants rate it higher probably due to rising energy prices which directly affects their disposable income but have no option genuinely for undertaking any renovation activities. This user-investor dilemma is one of the biggest structural challenges in the rented residential sector. However, the decision-makers have yet to find suitable answers. The energy performance certificate for advertising a property that is to be rent, has so far failed to provide tenants and landlords with equal information regarding the energy efficiency of the building in question. At the same time, investments in energy efficiency improvements have fallen [6]. There are no appropriate incentives for the different groups. First, according to the tenancy law, an annual rent can be increased by a maximum of 8 % of the investment costs for energy modernisation, which often exceeds the returns from such investments for tenants, at least in the short term. Second, owner-occupiers usually benefit directly from improved energy efficiency due to the saving on heating costs. Nevertheless, it is too short-sighted to base an assessment of economic profitability on this aspect alone. Often the utilization periods of properties are shorter than the payback periods of investments. Changes in value and thus market valuations of real estate must be included in the investor's calculations. Third, this is especially true for landlords. If at all, landlords benefit indirectly from an improved energy efficiency of their buildings through higher cold rents and shorter rental loss periods for new tenants.

Investments in improving energy efficiency are therefore even more strongly determined by a valuation on the housing market compared to owner-occupied dwellings [6].

Figure 2. Relevance of energy efficiency among the three surveyed groups over the last 6 years



How the factor relevance is being translated into action

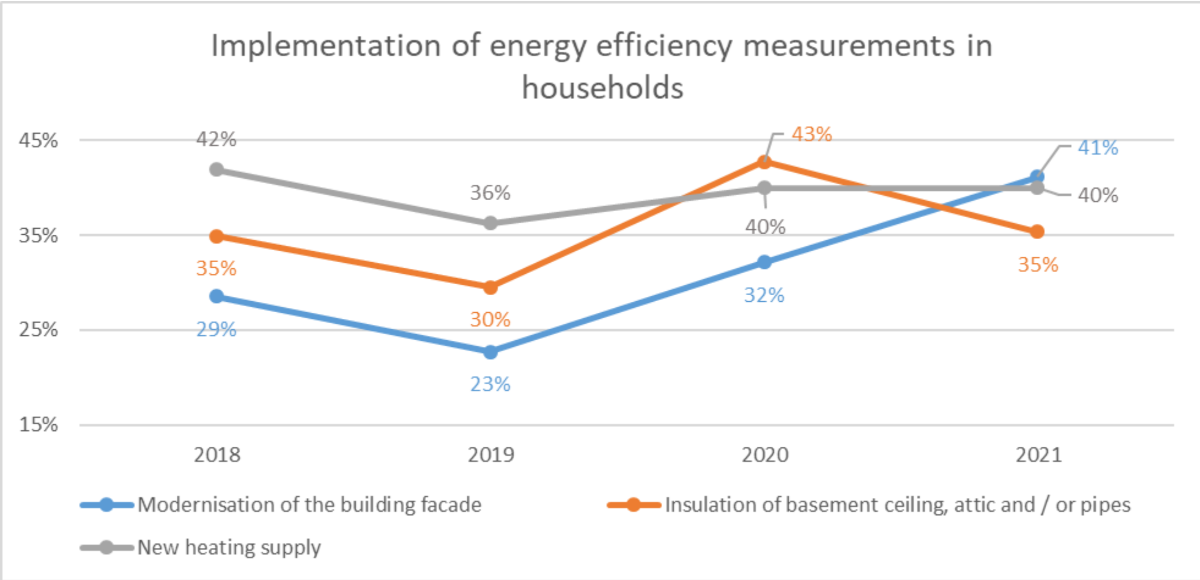
Implementation of energy efficiency measures in private households

To see how relevance plays out in the implementation of energy efficiency measures we take a look at the trends regarding the realisation of such measures in the last years (Figure 3). Figure 3 shows the three most often implemented activities in the last four years (2018 – 2021)[274] which were undertaken by all types of property owners (Table 2) in order to increase the energy savings of their buildings. Overall, we have stable tendencies regarding the implementation rates over the years with less than half of the surveyed undertaking energy efficiency measures. The implicit negative impact of less owners introducing energy efficiency measures is being counteracted by the ambitious level of the undertook actions. For the most part, property owners are oriented towards ambitious measures concerning energy efficiency such as heating systems and façades.

The most common realised measure is the instalment of a new heating supply system. On the one hand, this could be the result of a more attractive funding landscape in the last two years. For example, by the newly introduced Federal funding for efficient buildings (BEG) already more than 3,9 billion euros were distributed for energy renovation purposes in residential buildings in 2021 [4]. On the other hand, this could be a consequence of the anticipated rising in energy prices or a deadweight effect. Further follows the insulation of basement ceiling, attic and / or pipes with a decline of 5% in the last survey. In comparison to the modernisation of the building façade which rose considerably by 10% from 2020 to 2021.

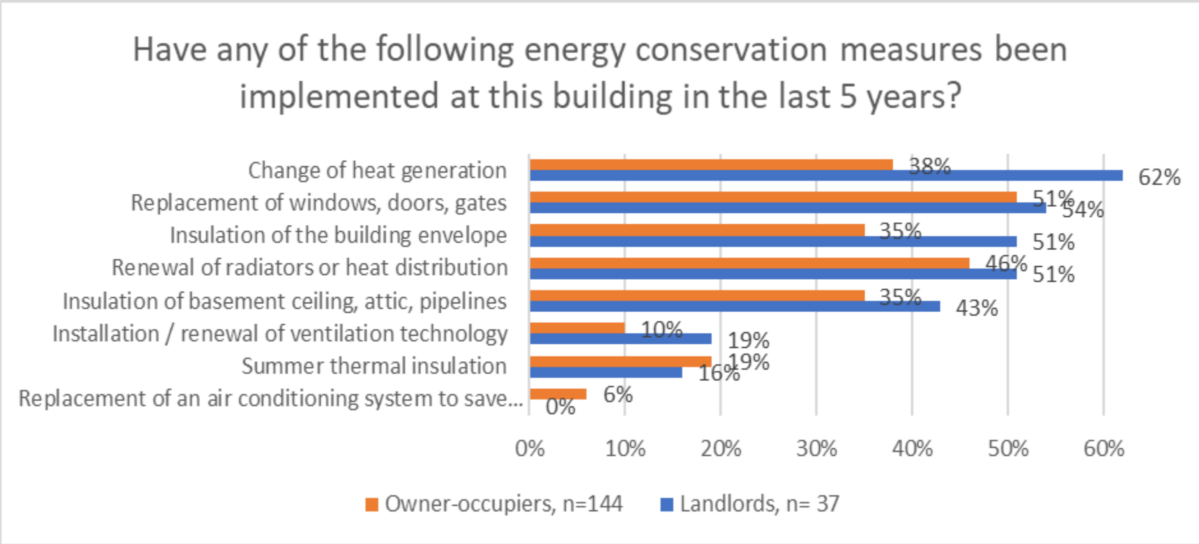
[274] This question was firstly introduced during the survey in 2018 and only to the group of property owners

Figure 3. The most common implemented energy efficiency measures by private households in the last years (only property owners)



For a better understanding of the motivation behind the implementation of energy saving measures, we offer a more detailed view of the realised measures in the last five years from 2016 until 2021 (Figure 4). For more valid findings the results are also being divided between the groups of landlords and owner-occupiers. We expect that these two groups would have different approaches towards energy efficiency. Due to the low number of answers by the landlords (number of frequencies is 47) we cannot make valid statements if they are in general more active than the owner-occupiers, but we can still identify tendencies where the particular focus of the groups is placed. The group of landlords shows by far a forerunner position regarding the change of heat generation (62 %) and the insulation of the building envelope (51 %). Something that interests only the group of the owner-occupiers is the replacement of the air conditioning system (6 %). The replacement of windows, doors, gates (51 %, 54 %), the renewal of radiators or heat distribution (46 %, 51 %) and the summer thermal insulation (19 %, 16%) are almost equally important to both groups. The insulation of basement ceiling, attic, pipelines (35 %, 43 %) and the installation or renewal of ventilation technology (10 %, 19 %) is being realised by both groups but slightly more often by landlords than owner-occupiers. In sum, we can support the argument that landlords tend to undertake more ambitious energy saving measures. An explanatory factor behind this tendency could be the energy certificates that landlords have to issue in order to rent out their property. Since 2014, an energy certificate, according to § 16a Energy Saving Ordinance (EnEV), is a mandatory part of a housing advertisement. Further explanatory factors will be discussed in the next chapter.

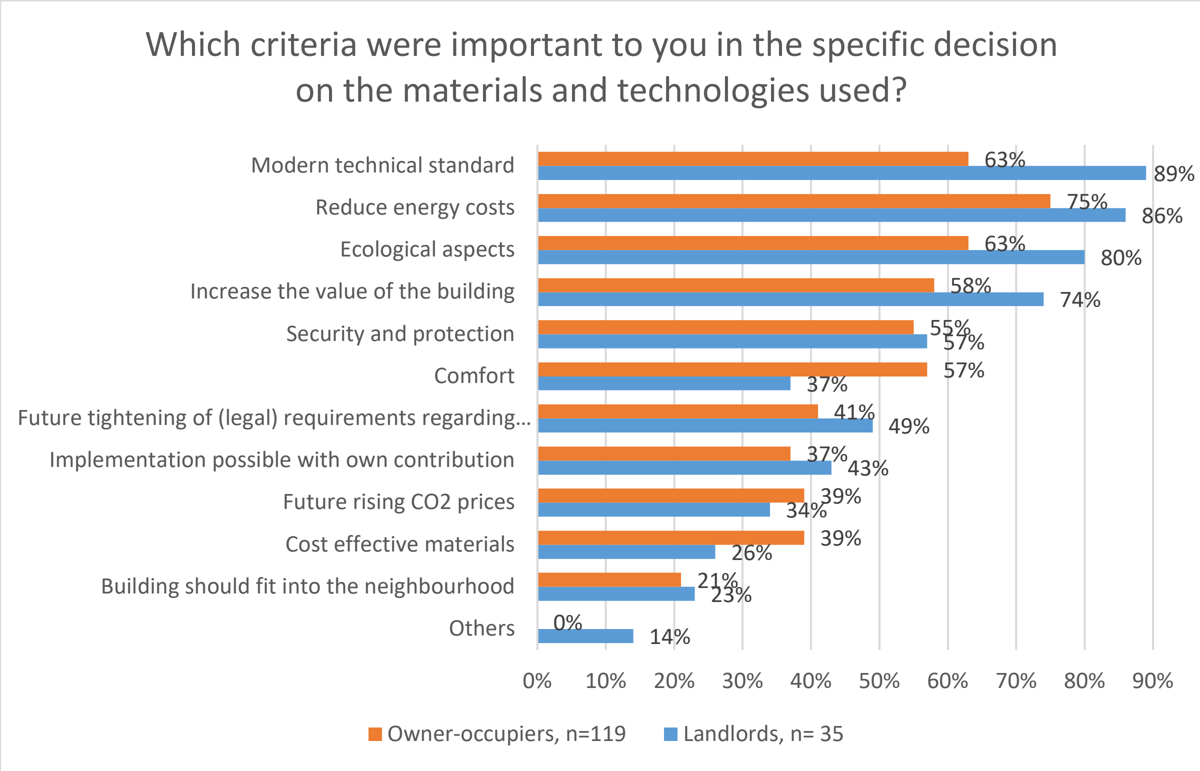
Figure 4. Implemented energy efficiency measures by landlords and owner-occupiers in 2021



Decisive criteria about the materials and technologies involved

To explain the already recognised tendencies in-depth and identify new ones, we offer the results from the 2021 survey regarding the significant criteria related to the decision for an implementation (Figure 5). In Figure 5 we again organise the answers of the property owners in the two groups of landlords and owners-occupiers. Interestingly, the strongest factor for both groups is the possible reduction of the energy costs (86 % and 75 %). However, as shown in Figure 5, we can identify some differences between the two groups. What seems important specifically for the landlords are a modern technical standard (89 %), ecological aspects (80 %) and an increase of the building's value (74 %). All three factors support the results in the previous findings (Figure 4) concerning the higher ambition level of implemented measures by landlords compared to owner-occupiers. In order to achieve greater energy efficiency in buildings modern technical and ecological standards should be considered. Additionally, these two factors support the increase in the property's value as well. The group of the owner-occupiers tends to focus on criteria such as comfort (57 %) and cost-effective materials (39 %). Almost equally relevant for both groups are further the issues of security (55 %, 57 %), future tightening of legal requirements (41 %, 49 %) and rising CO_2 prises (39 %, 34 %) as well as implementation with an own contribution (37 %, 43 %), which is also a cost saving factor and supports frequent mentions of cost-effectiveness. The groups of landlords and owner-occupiers differentiate clearly in their motivations towards energy efficiency. One focusing primarily on building's value, the other on comfort and cost-effectiveness. These findings point to a need for more group-specific incentive structures.

Figure 5. What were the significant factors for landlords and owner-occupiers in 2021?



Incentives and barriers for more energy efficiency in the residential building sector

Policy framework on European and German federal levels

In the beginning of 2021, the Federal Ministry for Economic Affairs and Energy has launched the 'Federal Funding for Efficient Buildings' (BEG) scheme. The program builds on existing programs and has been extended to boost the decarbonization in the residential building sector. It provides funding for renewable based heating systems and further measures that promote energy efficiency in buildings. Even before this launch of the BEG, the rates of funding in comparable schemes were increased substantially in January 2020. This led to extreme growth in applications to the programs. The applications for a program to promote solar thermal installations, biomass heating systems and heat pumps (the market incentive program MAP) from 2019 to 2020 have almost tripled. Because of this development the total available resources in the BEG for the year 2021 were increased to a total of 11.5 billion €.

At the European level several initiatives exist to enhance the energy performance of buildings. We see the following as important milestones: on December 15th 2021 the European Commission has published a proposal on the energy performance of buildings directive (EPBD) recast. The proposal contains several new instruments for achieving a zero-emission building stock by 2050.

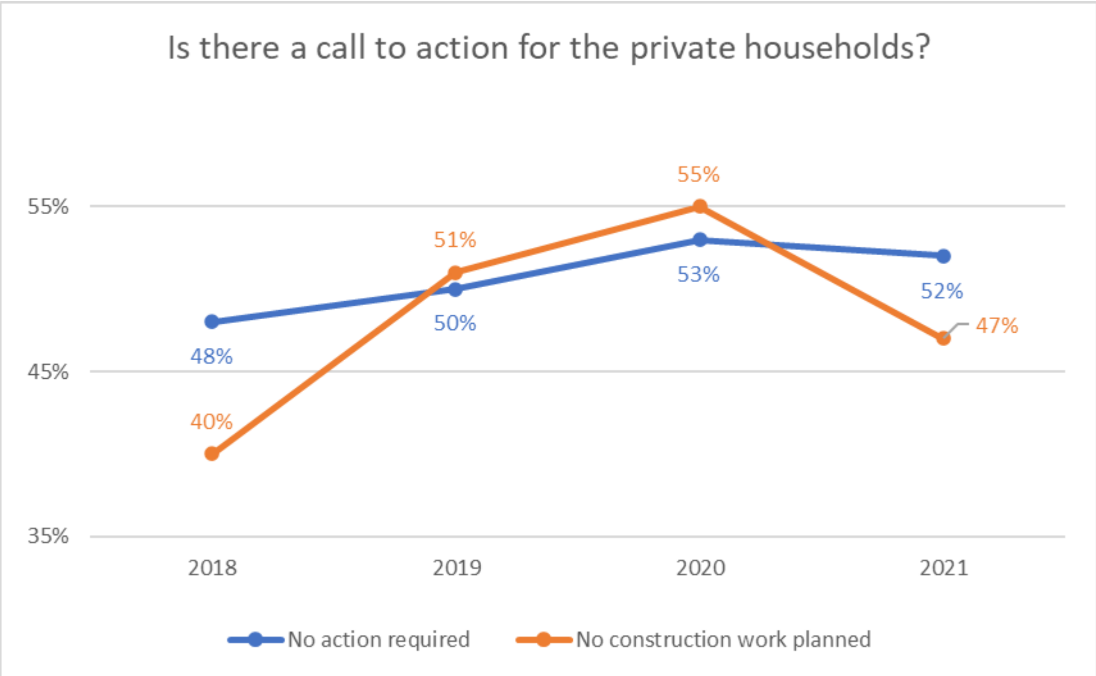
The first instrument that catches the eye are the minimum energy performance standards (MEPS) for existing buildings. The instrument targets the worst performing buildings and aims for an increase of renovation rates. Article 9 of the EPBD states, that Member States shall ensure that residential buildings and building units achieve at the latest after 1 January 2030, at least energy performance class F, and after 1 January 2033 at least energy performance class E. Buildings owned by public bodies and non-residential buildings must meet these terms three years prior to the residential buildings.

Another step the Commission hopes to trigger deep renovations is to define the term "deep renovation". The proposal defines a deep renovation as a renovation that transforms a building into a Nearly Zero-Energy Building (NZEB) until 2030 and into a zero-emission building from 1 January 2030. In addition, the proposal states, that Member States should give enhanced financial and administrative support to deep renovations.

Survey results on motivation and inhibition factors

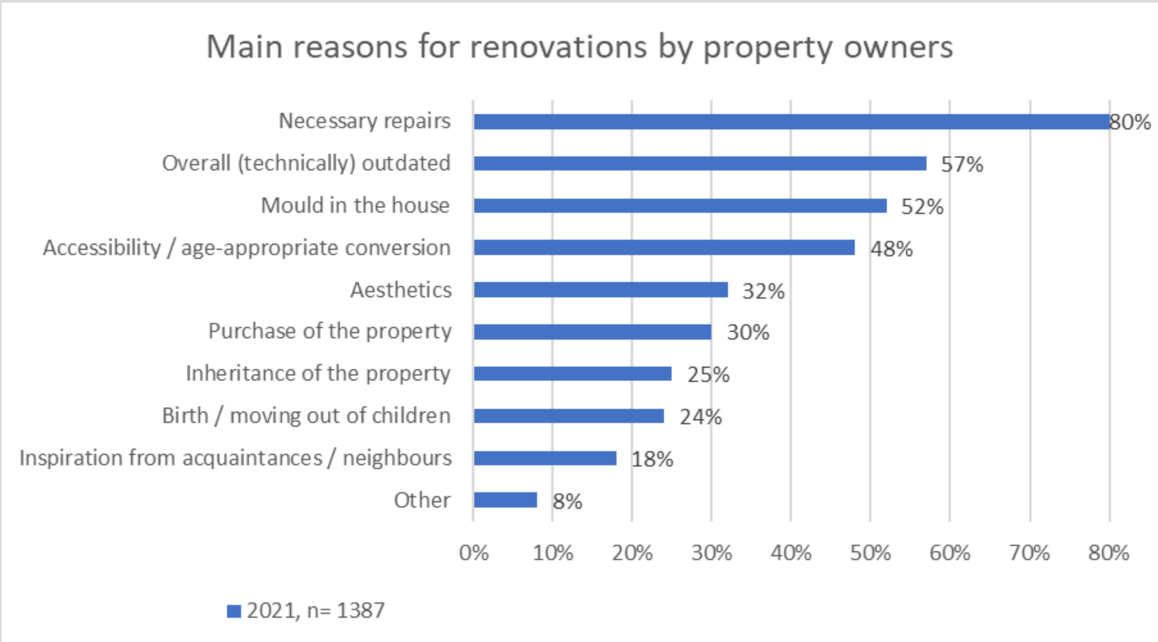
When asked about the reasons for implementing modernisation measures on the building the most frequent reason given by property owners was "to reduce energy costs" (Figure 5). However, most respondents assume that their building is in good condition. Over half of the households surveyed do not currently see any need for action on renovation measures. There is therefore a lack of incentive for modernisation. This is one of the strong barriers to implementing energy efficiency measures and consequently achieving more energy savings. Figure 6 shows the share of owners who do not plan any construction work soon and the share of owners who do not see any deficiencies regarding their properties. In sum, around half of the surveyed owners do not have any call to action.

Figure 6. (a) Share of private households that do not see any action required regarding their building condition (blue) and (b) share of private households that do not plan to undertake any construction work in the upcoming years (orange)



One way to successfully place the energy renovation with households that currently see no need for it is to link it to renovation events, as shown in Figure 7. Besides necessary repairs or the simple age of the building, adapted advisory products on the topics of mould or age-appropriate renovation can be promising approaches for advisory products advisory products. Furthermore, investments in energy efficiency often led to increases in comfort, health and productivity and are accompanied by other positive effects, which are clearly a priority of the owner-occupiers (Figure 5).

Figure 7. What were the main reasons behind the renovation measures?



Another enabling factor are the energy efficiency services. In the following chapter, we take a closer look at their impact on the implementation rates and investments towards energy efficiency of private households.

Role of energy efficiency services

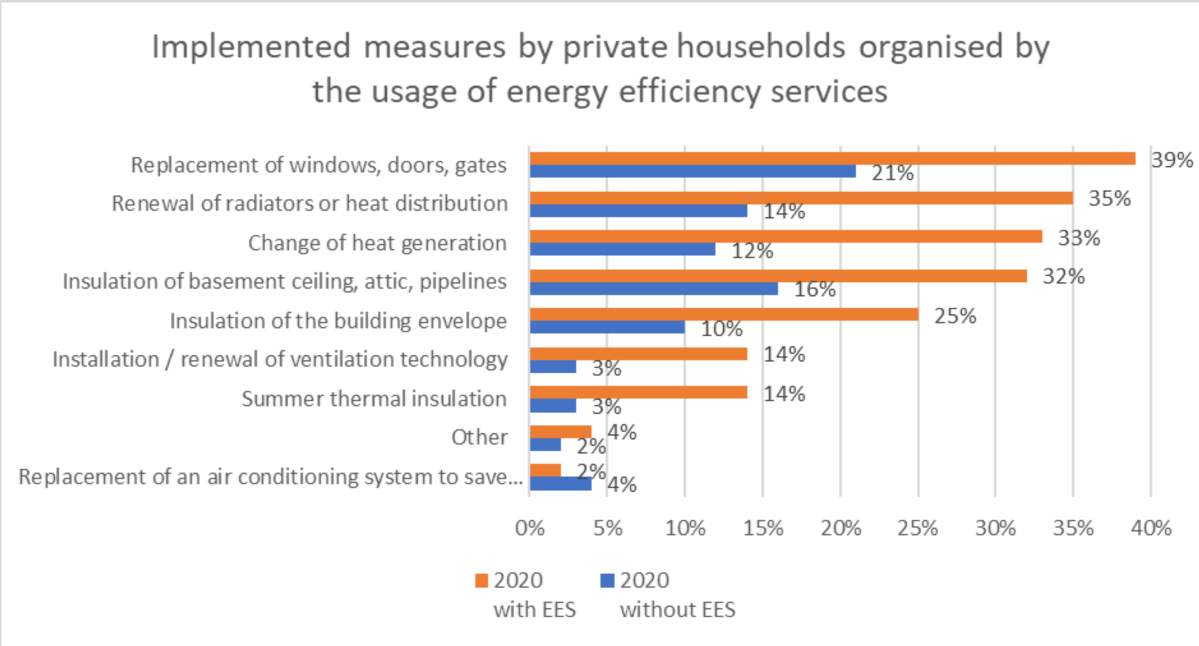
Why are energy efficiency services important?

We have compared the number of implemented measures by private households which have used energy efficiency services, and which have not. In the survey of 2021, we have a clear tendency regarding the positive impact of energy efficiency services in this matter. Of all the households which used such services in the last 5 years more than 72 % also realised energy saving measures [1].

Furthermore, we have compared the investments private households made in increasing the energy efficiency and their usage of energy efficiency services. Here we were as well able to identify a positive impact. The households which used such services invested in energy efficiency five times more in 2021 than the others [1].

Figure 10 offers a more detailed view on the impact of energy services. First, it is to be noted that the households which used such services implement by far more often energy saving measures than the other households. Second, they implement quite more often comprehensive measures such as changing the heat generation or insulating the building envelope in comparison with the households which did not use energy efficiency services (Figure 10).

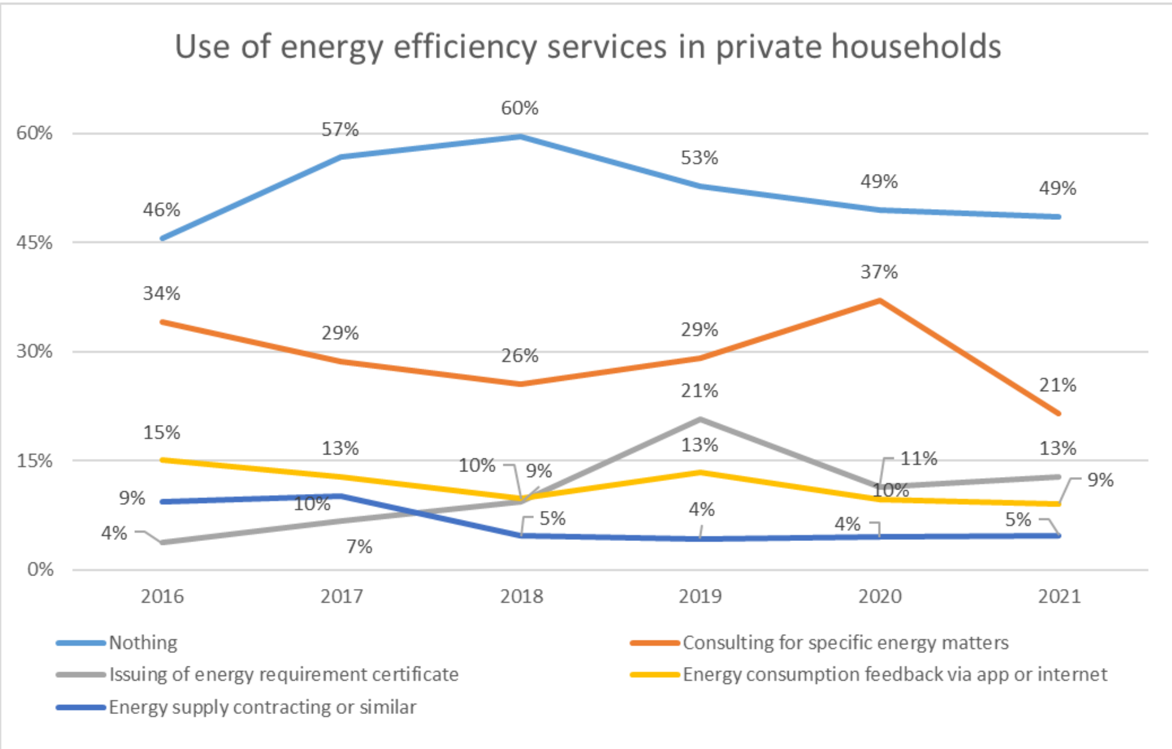
Figure 10. Measures implemented by private households according to the use of energy efficiency services



Usage of energy efficiency services by private households

Over the years we have a slightly declining but still strong negative trend concerning the usage of energy efficiency services in private households (Figure 11). Half of the surveyed households did not use any services at all (varies between 46 % and 60 %).

Figure 11. Use of energy services in private households, monitoring reports from 2016 to 2021



Generally, for owner households the most important points of criticism concerning energy consultancy services is that the advice provided little new information (42 % of respondents who expressed criticism), that the expected savings could not be realised (33 %) or that the cost-benefit ratio was poor (32 %). Further, owner households that do not want to use energy consultancy were asked about the reasons for this. Multiple answers were possible. The most common reasons were that they felt there was no need for action on the building ("I am not planning any construction measures on the building", 55 %) or that questions on the topic would rather be clarified without an advisor (45 %). This proportion has increased compared to previous surveys. Aftermaths of the Covid-19 pandemic situation could also play a role here. Also, frequently mentioned, were the already low energy costs (39 %) or that the added value of the advice was not recognizable (38 %). Market structure reasons only play a subordinate role. Less than 10 % of the respondents said that they did not know where to turn (8 %), that energy advice generally has a bad reputation (7 %) or that friends and acquaintances had advised against using it because of their own bad experience (5 %) [1].

Figure 12 shows the willingness of owner households to pay for professional energy consultancy. Compared to previous years, the willingness to pay has increased in the categories of “up to 1000 euros” and “more than 1.000 euros. Still, the proportion of these two categories is twice as little as the categories “up to 200 euros” and “up to 500 euros”. This is a challenge, since these diverge strongly from the market price. The average price for energy consultancy in residential buildings is relatively stable over the years and varies between 1.100 and 1.410 euros for a consultation (BfEE years examined: 2016, 2017, 2018 and 2019).

Tenant households were only asked whether they had to pay for the consultation, not about the possible costs. However, the fact that tenant households use consultation for which they have to pay is an absolute exception (less than 2 % of the surveyed tenants who used such services) which mainly is due to available federal funding. Details about the funding is given in figure 13 below.

Figure 12. How much money are you willing to spend on energy advice from an expert?

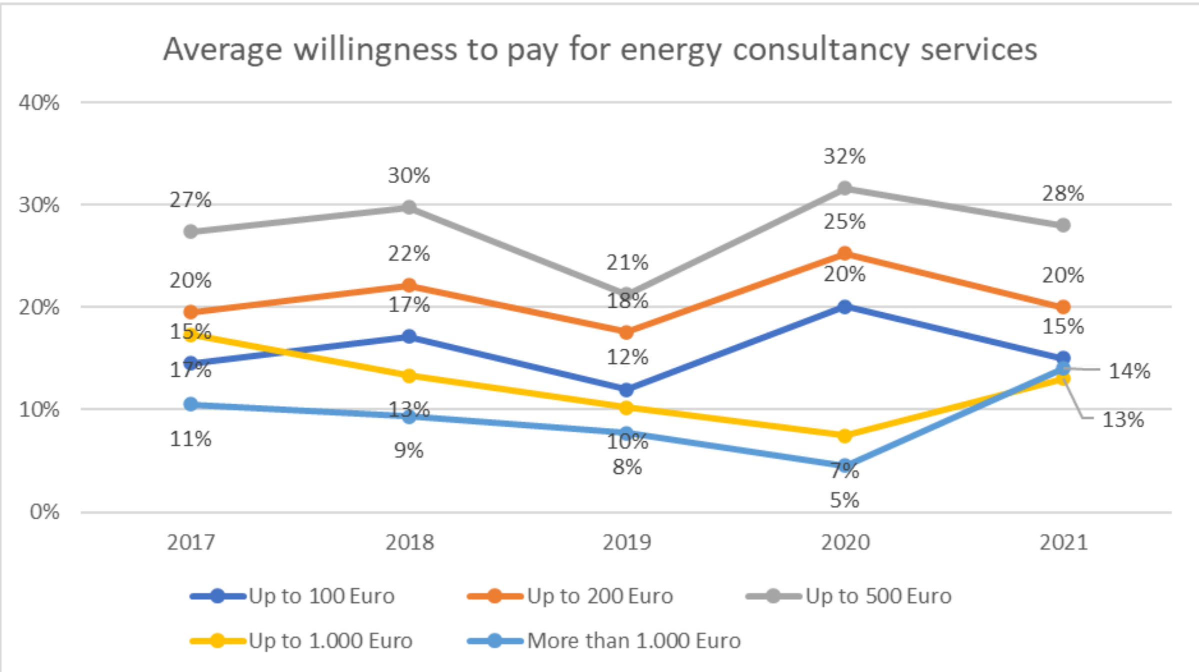
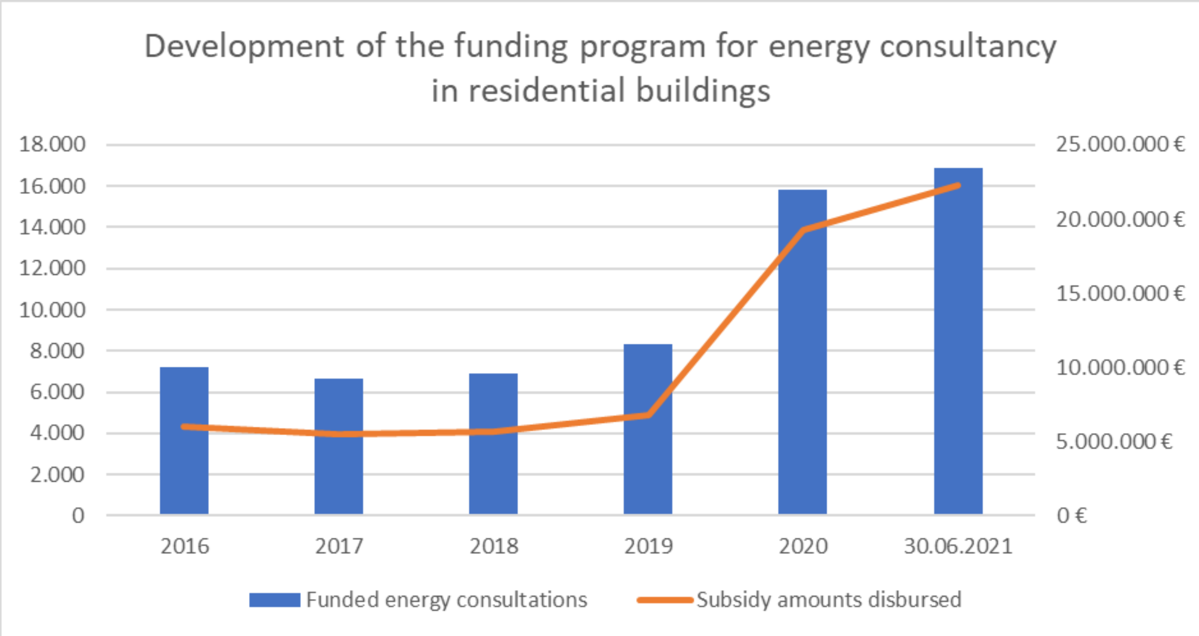


Figure 13. Federal Funding Program for Energy consultancy, BAFA statistics



Summary and conclusions

The residential sector offers a great potential for energy savings. On the one hand, the subject of efficiency enjoys high relevance rates (around 7 out of 10) among the different groups of private households, which stands out against other surveyed groups. On the other hand, there is a consensus among tenants and landowners regarding the importance of reducing energy costs, even if for different reasons: to save money or increase property value. Still, implementation rates of energy saving measures from landowners are stagnating at a level of appr. 40 % over the last years, what points in the direction that there is a need for more group-specific incentive structures.

The policy framework already put strong incentives in place. First, in 2021 the funding landscape was reformed, and more attractive funding rates for landowners are offered. Second, and also since 2021 there is a price signal of the introduced national carbon pricing system specifically in the heating sector (Fuel Emissions Trading Act). Third, more energy renovations must be realised by landowners in future years due to the new requirements of the EPBD, which have yet to be implemented in national law. Consequently, the implemented measures in households are expected to increase.

In this context, energy efficiency services are the driving factor behind higher investments and the professional realisation of energy saving measures. Their expertise can help property owners identify the call to action, find the right solutions and even realise them. This was the reason behind the linkage of investment and advisory funding. The skyrocketing development of the Federal funding program for energy consultancy demonstrates the expected effect (Figure 13). However, there is an untapped potential for energy efficiency services in the residential sector as can be seen from the current low usage rates. This may be activated via more communication campaigns and the linkage of energy consultancy services with the specific drivers and incentives for each group but is still subject of further research.

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9 DEMAND RESPONSE AND RENEWABLE ENERGIES

Verification of Demand Response: the customer baseline load in small/medium customers

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Abstract

The development of Demand Response (DR) is a basic step to achieve an increase of the flexibility in Power Systems, in the short and medium, term to balance the volatility of the new generation mix foreseen in the horizon 2020. At the same time, it is necessary to deploy tools to evaluate the performance of DR policies to obtain precise economic feedback for all the actors. This should increase the engagement of new resources from the demand-side. The verification of DR involves a right estimation of the customers' steady-state load without control: the customer baseline load (CBL). The aim of this paper is to compare the accuracy of the traditional and simple methods based on historical data to calculate CBLs with a specific Neural Network based method and, with both methods test the significance of adjustment coefficients in the increase of the accuracy or results. To develop this proposal, a demand database from a SME customer in the south east of Spain is analysed. Results show that it is possible to improve the performance of CBLs without increasing their complexity, which enables the removal of some technical barriers of more complex baseline approaches.

1. Introduction

A main concern for energy actors and authorities is the development of the portfolio of Demand Response (DR) on an equal footing with respect to conventional Supply-Side resources and integrate in this portfolio new resources (Distributed Energy Resources, DER) such as Energy Storage Systems (ESS) and Renewable Energy Systems (RES). For instance, the article 17 of the EU Directive 2019/944 establishes that "Member States shall allow final customers, including those offering DR through aggregation, to participate alongside producers in a non-discriminatory manner in all electricity markets" [1]. This issue includes the payment for the resource's performance, but the flexibility must be measured and verified in an easy and right way.

The achievement of this objective requires accurate and understandable economic flows: customers should receive credit according to the flexibility they provide, which needs an accurate evaluation of the changes in demand that occurs after DR performs. A forecast of demand (demand and generation, in the case of "prosumers") considering loads and other DER resources is needed. The physical behavior of loads and customers can change due to several parameters: weather, type of day, end-use shares, gaming possibilities and, specifically, the frequency of activation of DR events. Aggregators, Load Serving Entities (LSE) and System Operators (DSOs or TSOs) should estimate the "steady-state" of loads of their customers without DR (that is, the so-called Customer Baseline Load, CBL) with respect to available Smart Meter (SM) measurements after DR.

Several attributes are theoretically required for a good CBL: accuracy, simplicity, replicability and integrity. The accuracy of both the baseline estimation and the achieved flexibility is important to avoid erroneous incentives or penalties for DR and, in this way, promoting and encouraging customer participation. The accuracy is a main concern because the interest in DR may be reduced on the premise that management and enabling technology costs (e.g., smart thermostats and control) are usually high, and this casts a doubt on the recovery of the investment made in those enabling technologies. These issues have been a determining factor (a barrier, as stated in [2]) for the reduced participation of customers in implicit DR (price-response). For instance, in New York ISO there was some historical participation since 2006 [3] and a considerable interest in Demand Side Flexibility (DSF) to price, but during 2017 there was not any active price participation in the NY. Other power systems have a similar experience and the estimated revenue for economic DR (implicit DR) are quite small in comparison with capacity payments for explicit DR. For example, these figures have been reported by PJM in the USA [4].

Moreover, a CBL methodology must be robust to avoid some manipulation attempts of specific customers or entities, more interested in gaming than in DR. Forced changes in patterns to alter revenues should be detected by CBL to ensure DR integrity and a fair and correct revenue. Besides, CBL methodology should be simple to be understanded by customers, and this methodology should consider the idiosyncrasy of customers and markets where DR is deployed. If CBL is too complex it becomes a barrier, it could lead to a lack of interest by aggregators and customers. CBL should be also replicable, in the sense that we need some degree of standardization in CBL, to avoid the development of specific methodologies for each customer, country, product and market. Therefore, it is significant that regulators could provide different methods to compute CBL and agree with the other parties (customer and aggregator) a specific method. This seems a possibility to increase the customer engagement in DR policies and mitigate gaming. This option is usually deployed by operators and utilities (e.g., the notification of DR mechanisms, in France [5]).

The rest of the paper is organized as follows. Section 2 deals with the literature review of CBLs. In Section 3, different CBLs are revisited, and their adjustments are introduced. Section 4 outlines the case study (a commercial customer) through two different methodologies and the results obtained for the case study when the proposed methods are applied. Section 5 presents the conclusions.

2. Literature Review

The increase in renewable generation, and the objective of decarbonisation by 2030-2050 in most of countries around the world, will increase the interest of DR policies in wholesale, retail and future local markets. The measurement and verification of DR is a main concern for the effective engagement of new DR/DSF resources and, consequently, the interest in the development of CBL calculation methodologies has gained momentum since the last decade. At the same time, the figure of aggregators has increased its importance in the European Union. Some examples are France and Spain, where the aggregation is (or will be) more complex due to higher imposed thresholds to responsive demand capacity (around 1 MW) with respect to power systems in the USA (100 kW). These limits can be a problem for customers and aggregators and require the verification of the response (flexibility) for the qualification of responsive resources. This is another complex requirement for small and medium customer segments.

Most of methods described in the literature [6], [7], involve two steps in the definition of CBLs. First, the definition of the base profile and, second, an adjustment method to refine the initial estimation of demand, especially when the load is sensitive to external inputs, for instance: temperature, humidity or solar radiation in weather sensitive loads (air conditioning, heating, water heating, food storage…).

The success of DR policies since 2005 means that payments have increased [8], for example from $50 million to $500 million in 2021 (PJM [4]), so more precision is required in the evaluation of the economic side of DR. The interest and importance of this issue in the USA, Australia or Europe arise from a review of different reports and projects dealing with baseline as a topic in their activities. Research laboratories [9], [10], research consortia [11], [12], power system operators [6], [7], aggregators [13], utilities [14], [15], and energy and environmental agencies [16], have defined and analysed different types of baselines, their metrics, and have proposed some methods to improve their accuracy. This proliferation of methodologies, sometimes for specific customers and systems, has made more complex the management of DR [17] and the participation of small and medium customers (e.g., SMEs) which must be aggregated. The standardization and simplification of CBL methodologies arise as a necessity to remove DR barriers [2]. These attempts start in 2009 by the North American Energy Standard Board which proposed a series of definitions for CBLs to improve the harmonization of CBL methodologies. Later, US authorities assumed these definitions [18], [19]. For instance, the US ISO/RTO council periodically summarizes a table [20] that lists the description, measurement and verification parameters for DR programs across different ISOs.

Literature also depicts methods for different customer segments and regions, and some of them establish comparisons between these baselines. Lawrence Berkeley reported in [9] some methods for non-residential buildings. This research confirmed that base profile benefits its performance with adjustments before the DR period, but they recommend the use of different models for different groups of loads (due to the different weather sensitivity of loads in each segment). In [15] conEdison reported that simple baselines (e.g., High3of5 or Mid5of10) usually perform well for different segments, but when more sophisticated methods are used in a customer segment (e.g., regression analysis for a customer segment), it appears inherently inaccurate for other individual customers and days. This is especially significant for small customers, mainly for residential consumers. Similar results are reported in [14] by San Diego Gas & Electric. Authors conclude that any method is close to being accurate for individual customers on individual event days. In conclusion, more complex baselines only provide marginal improvements in accuracy but at a higher computational cost.

In [21], authors present different methods to evaluate the base profile of demand, from white-box to black-box models, but without any estimation of relative accuracy. Nevertheless, authors state that the accuracy of black-box methods depends on the training procedure, which must be repeated anytime a physical change of the system occurs, which makes more complex the aggregation. In [22] authors propose the so called "control group" approach, i.e. the clustering of customers onto different groups according to consumption patterns to reduce the randomness of individual demands and improve the performance of CBL. This method also presents some drawbacks [23] because it may be hard to uniquely define the best control group that properly captures the customer behavior of the DR group of participants. Basically, the necessary classification of demand into homogeneous, quasi-homogeneous or heterogeneous groups is a conclusion previously established in DR planning and management [24], [25]. This fact is important because it demonstrates that DR operation and verification should share common methodologies and procedures, and this can simplify DR, especially when aggregation of customers is needed.

It is interesting to note that short-term load forecasting (STLF) shares common methodologies with CBL methods because both provide demand forecasts in the short-term. STLF comprises multiple methodologies, for example, linear regression and Artificial Neural Networks (ANN) which can also be used to calculate CBLs [26], [27]. Some other machine learning methods such as Support Vector Regression (SVR) and Support Vector Machine (SVM) have been employed to forecast demand in [28]–[30]. Hybrid parameter optimization [28] and ant colony optimization [29] have been proposed to find the optimal parameters for SVR, whereas SVM with simulated annealing has been presented in [30]. The efficiency of ensemble methods based on regression trees, such as random forest or boosting, have been analysed in [31]. Nevertheless, classical methods like ARIMA models still perform well for demand forecasts. For this reason, hybrid models that combine two or more different methodologies (ARIMA, SVM or ANN) outlined good results. For instance, SVM and ARIMA are proposed in [32], [33], and the combination of ANN and SVM has been developed in [34]. A machine learning approach to disaggregate load and photovoltaic (PV) generation from net load data is analysed in [35] to obtain CBLs in prosumers. Authors conclude that reducing errors in the PV output power estimation can improve the CBLs performance. In [23], authors use Gaussian Process regression for machine learning because they state that the drawback of deterministic methods lies in their failure in capturing the dynamics of complex user behaviors, particularly important for small to medium consumers with more variability.

3. Methodology

3.1. Overall methodology

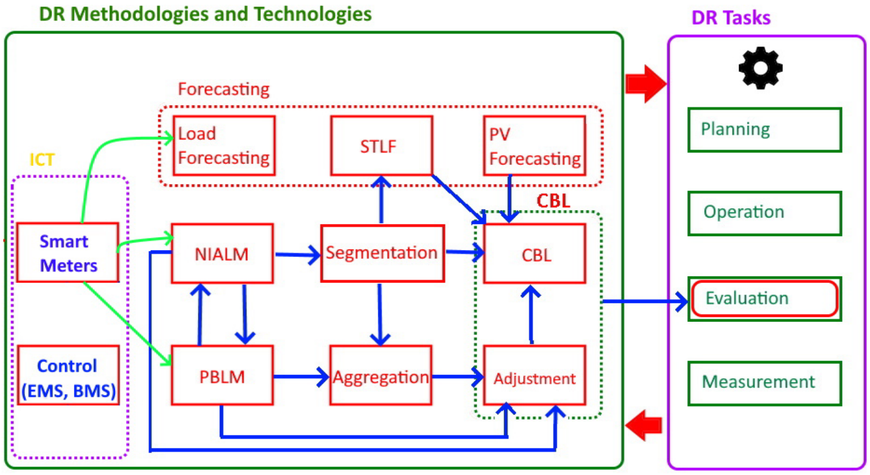
The increase of power systems flexibility in the scenario 2030-50 is based in the flexibility of Demand-Side resources. Four tasks are critical for these resources (specifically for DR): planning, operation, measurement and verification (figure 1). The proposal of this paper is that there are different methodologies that can be used for each task, and, at the same time, some methodologies can be used for more than one task. These synergies among DR tasks can make their management easier. Figure 1 shows a layout of this idea and the interconnections between DR methodologies, developed by the Spanish Research Network REDYD2050.

The evaluation and deployment of DR potential need the use of load or end-use models, such as Physical-Based Load Modeling (PBLM, considered as “grey” or “white” models). Another important issue to determine the potential of flexibility (demand reduction levels, loss of load service, rate of change of demand, energy recovery/snapback…) is the determination of the aggregated response [36] at several levels (from homogeneous to heterogeneous groups of loads, or between loads and other DER resources). Aggregators need some tools to perform DR simulations before the DR event for planning the operation of the responsive loads (usually loads with some kind of energy or product storage [37] such as HVAC, WH, ice or heat storage tanks). In this context, Non-Intrusive Load Monitoring, NIALM, plays an important role. NIALM allows to obtain the end-use demand to tune and validate the parameters of PBLM models, as well as the definition of average end-use patterns (i.e., the calculation of elemental load baselines [38] in customers where sub-metering is not available or not affordable from the point of view of costs), all of them from SM measurements (figure 1).

Regarding the participation in markets (wholesale or local energy markets [39]): the aggregator needs load forecasts to define the energy requirements in day-ahead markets and avoid penalties in balance markets. This can be done through specific forecasts [31], but CBLs can also be used. Weather or gains in efficiency can be evaluated from modelling if these models are physical based. Finally, NIALM should contribute to the verification of the performance of responsive loads before DR (to detect potential gaming) or during DR (load flexibility).

As it has been discussed in section 2, segmentation methods can be crucial for achieving a refinement and a gain in CBL performance, but it is also important to perform load aggregation and evaluate their DR potential [40]. STLF and CBL can also provide feedback for PBLM toolboxes (e.g., the change in customer behaviour due to market prices or due to frequency in event calls) which are common tools for day-to-day operation of aggregators. It is also worth mentioning the linkage in the opposite sense, which is further considered in the adjustment of CBL as it has been proposed in [40].

Figure 1. Interaction among PBLM, CBL, NIALM and STLF tools according to [25] for evaluation purposes in DR.



3.2. Characteristics and methodologies for baselines

As stated in section 2, a main problem with baselines is the lack of standardization. For this reason, the literature describes different CBL methodologies. Some of these, developed "ad hoc", can have excellent results for its specific segments, DR products, markets and situations, but they can fail in different scenarios [18], such as prosumers, small/medium customers or customers with a high share of weather-sensitive loads (for example, commercial customers of buildings). Literature states that "base-profile" baseline methods based on the use of historical data are a sufficient approach for obtaining a good and simple basis to further develop CBLs with high accuracy through adjustment.

US Power Systems have two decades of experience with DR in different markets and consequently with CBL methodologies and their problems and implementation barriers. To overcome these problems, NAESB defined in 2009 five types of methodologies [24]: Maximum Base-Load; Baseline Type-I; Baseline Type-II; Meter Before/Meter After and Metering Generation Output.

Baselines Type-I&II have been adopted as default methodologies by several ISOs, [41]. The Type-I is based on historical demand data, which may also include other variables such as weather and calendar. The Type-II assumes the same idea, but it uses statistical sampling to estimate the aggregated consumption. With the deployment of Smart Meters in last decade [6], [25], this methodology lacks a practical interest. The most common CBLs in the literature are briefly described.

1. <u>Maximum-Base Load (Firm Service Level):</u> is based on the ability of a resource (DER) to reduce its consumption to a specified level: the so-called in some systems as Firm Service Level. The customer should keep is demand below this level to avoid some penalties. Sometimes it is also known as the "non-baseline".

2. *<u>Y-day Simple Average Method:</u>* to predict the CBL, the method uses the average demand over the Y most recent non-DR days immediately before the DR event being considered. Usually from 3-day to 10-day-basis are used for this estimation [42].

3. *<u>Comparable Day Method:</u>* this also considers historical demand data to compute the CBL. In this case, the method only takes one day that is selected for its similar conditions with the event day (temperature, humidity, day of the week…). If sufficient relevant factors are not considered, the forecast trend to be erroneous.

4. *<u>High/Middle/Low XofY baseline:</u>* the baseline is obtained again by averaging recent historical data. It considers the demand of Y non-DR days preceding the DR event and it uses the average of the X days with the highest (or middle, or lowest) demand within those Y previous days. These baselines apply the so-called exclusion rules [19] (i.e., some days are not considered for the evaluation),

because operators assume that some variables can modify the pattern of demand. Up to 30 or 60 days can be used to define Y [13], but usually shorter periods such as 3, 5 or 10 days are used because long periods could include too much changes in the demand pattern (especially for sensitive loads). The use of High, Low or Middle depends on their use. HighXofY is the most common if DR events are due to peak load periods. Some practical examples of these baselines are High5of10 in California SO [7] or High15of20 in IESO, Canada [20]. These CBLs are calculated as follows:

$$CBL_{XofY}(d,h) = \frac{1}{X}\sum_{i=1}^{X} A\,(i,h) \qquad (1)$$

where $CBL_{XofY}(d,h)$ is the baseline at time h of day d; A(i,h) is the actual load for the i-th highest (middle/lowest) energy day, at time h, among the previous Y non-event days, and X the number of the highest (middle/lowest) days to be averaged in Y after exclusions.

5. *Nearest XofY baseline:* it focuses on the total consumption outside the DR event window to determine which of the Y previous days are more like the event day. The X days (inside the Y interval) having the closest demand to the DR day are selected. Then, the baseline is computed as the average demand of these X days. Exclusion days are also applied.

6. *Weighted Average method:* this is based on a weighted average of the previous day's CBL (some of the above CBL_{XofY}). For instance, this method is used in Korea by KPX [43]. In this case, among the 10 reference days, the two highest and lowest days are excluded, and the remainder is used with different weights. For example, KPX define weights such as 0.10, 0.15, 0.15, 0.20, and 0.25 ranging from the older demand to the most recent demand. The main problem is the estimation of weights, depending on the country and customer segment.

7. *Exponential Moving Average:* a weighted average of customer historical demand is considered again in this option, but the weight decreases exponentially with time. The main difference with the previous CBL is that it considers a broader spectrum for "X" days.

8. *Control Group Methods:* the method considers the possibility that the aggregator (or other power agent) has a demand database with other non-responsive customers (in the same segment) from the DR event day. The customers are clustered in similar groups and the DR customer's load curve is matched to one of these groups. Then, the CBL is calculated by averaging the load curves in the selected cluster in per unit. More complex methods can use a weighted combination of load curves in the cluster, or the load curves of the same customer and other customers on non-DR event days [44].

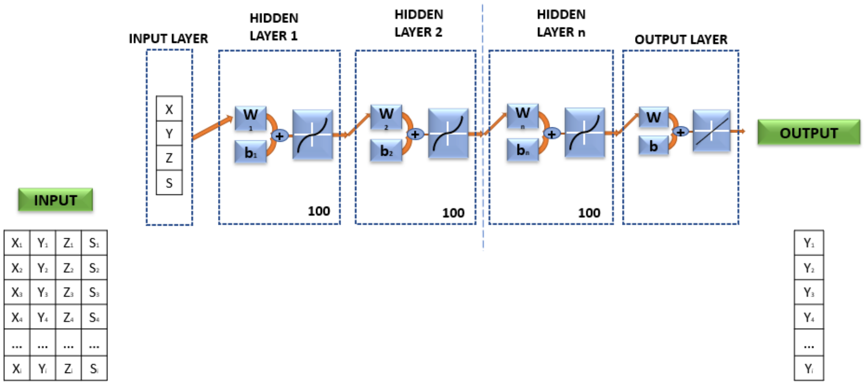
9. *Short-term load forecasting methods:* this cluster of methods comprises a wide range of alternatives. For example, the CBL can be built using a customer-specific regression model, that besides historical loads also weather conditions and calendar features (holidays, season, day of the week…) are considered. In [42], CBL is estimated for campus buildings and with a high penetration of weather sensitive loads (e.g., HVAC). For that, a linear model is fitted over the 5-minute period just before the DR event and the 5-minute period immediately following the set time. Another example, is the use of Neural Networks (NN) to estimate the CBL (a back propagation NN [27], [45]) where NN is adapted to establish baselines in public buildings (South Korea and China, respectively), considering meteorological indices. The close relationship between CBL estimation and STLF models allows that many other methods (e.g., random forest) could be considered as an approach to compute the CBL.

3.3. Neural Network method proposed

Neural networks can be classified as a series of algorithms that endeavour to recognize underlying relationships in a set of data. To compare traditional methods with more advanced techniques for obtaining CBLs, different tests with NN of different complexity have been developed. One-layer, two-layer and three-layer networks will be tested, with different number of neurons, a fixed number of samples for training, validation and testing, and three of the most common used training algorithms: Levenberg-Marquardt (LM) [46], Bayesian Regularization (BR) [47] and Scaled Conjugate Gradient (SCG) [48].The input and output layers just pass on/out the information to/from the hidden layers, whereas these apply the sigmoid activation function.

Data from a commercial premise in the service sector in the south-east of Spain will be used, 2017 and 2018 data are used as the training validation and verification set for the NN (60/20/20 ratio used), and 2019 data for testing the performance of the NN. In order to have a higher degree of correlation with traditional methods, we will use calendar data as input to the neural network. Four input variables repeated for each hour are established. Namely, the hour number from 0 to 23, the day of the month from 1 to 31, the month of the year from 1 to 12, and the type of day of the week from 1 to 7. To reduce the input noise, type 1 days (Sundays) are not considered. This is because, on this day, most of the commercial premises are closed. Therefore, DR measures cannot be applied. As output, we have the value of the hourly power demand in kW. Consequently, there are five types of variables counting the inputs and the output for each hour of the year.

Figure 2. Structure of a Neural Network with four input parameters and one output.



Before obtaining the final solution, the use of other variables as an input was investigated. Variables such as hourly temperature, or whether the type of day is a holiday or not, have been tested to develop the NN. However, the inclusion of these variables was returning similar results in the prediction, so finally they are not considered in the current research. It is considered that the 4 inputs variables that are explained before (hour number, day number, month number and type of day) are enough to develop the NN as including the weather conditions do not improve the performance of the NN.

3.4. The adjustment of baselines

The base profile defined by the baseline can be improved using adjustment methods that consider the possibility that demand could change in the short-term with respect the first estimation done by the methods described in paragraph 3.2. There are two main methods: multiplicative and additive adjustment that basically represent the same idea. The objective of these adjustments is to modify the preliminary CBL to adapt it to weather and demand conditions on the DR event day. The easiest way to evaluate these factors is the use of pre-event DR data, and then calibrate the baseline using the observed non-event hours prior to DR periods. In [9] the adjustment factor is defined by:

$$amf(d) = \frac{\sum_{k=1}^{a1} A(d, h_0 - (b1 + k))}{\sum_{k=1}^{a1} P(d, h_0 - (b1 + k))} \quad (2)$$

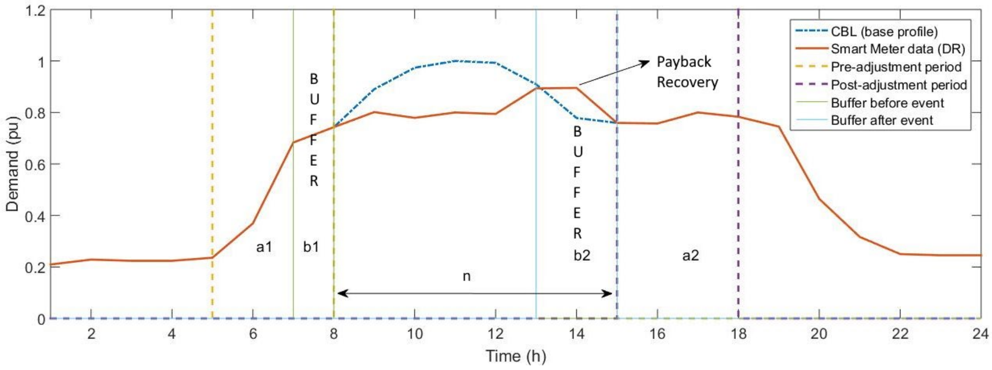
where *amf(d)* denotes the adjusted multiplicative factor for the day *d*; *A(d, h)* is again the actual load of day *d* at time *h*; *P(d,h)* is the predicted load (from unadjusted baseline or short-term load forecasting methods [31]) of day *d* at time *h*; *h0* is the start time of the DR event; *b1* is the buffer-time and *a1* is the length of the pre-adjustment band (Figure 3). Then, the new CBL is evaluated by:

$$CBL_{adj}(d,h) = amf(d) * CBL(d,h) \quad (3)$$

Some SOs uses pre and post DR adjustment factors combined in the same baseline [7]. The idea is that the post-event factor gives additional information about the boundary conditions throughout the DR-event day (e.g., weather changes that modify demand). CAISO Baseline Accuracy Work Group justifies this approach to avoid contamination of baseline both for pre-cooling and snapback periods to occur in the hours directly before and after the DR event [7].

Figure 3 depicts this idea. In this case, the DR event period ranges from 8:00 to 13:00 and the pre-adjustment period uses data from 5:00 to 7:00 (*a1=2h*) while the post-adjustment period uses data from 15:00 to 18:00 (*a2=3h*). Obviously, these periods do not overlap. The consideration of two periods (pre buffer *b1=1h* and post buffer *b2=2h*), limits the possibility of perturbations like gaming just before the baseline method takes demand data from SM to adjust its forecast. Pre-adjustment buffers are applied in several systems in the USA (e.g., NYISO [49] which uses a two hours buffer *b1*). It seems necessary that the definition and the duration of both "buffers" should be justified by load mix and behaviour (e.g., through load modelling, the approach proposed in [40]). In Figure 3, *n* represents the period in which the consumption is affected by the DR event, that is, the sum of de DR period and the post-buffer period.

Figure 3. Example of baseline adjustment and periods being used in equation (2)



3.5. Evaluation of CBLs performance

Regarding the error metrics, the Mean Percent Error (MPE) has been selected to describe the magnitude and direction of the estimation bias. MPE reflects the percentage by which the baseline, on average, over or underestimates the "true demand" in absence of a DR event. To evaluate the precision, both the Mean Percent Average Error (MAPE) and the normalized Root Mean Squared Error (nRMSE) have been selected. The lower MAPE and nRMSE are, the more precise the baseline is. Note that metrics are defined through relative errors, so they can be used to compare accuracy and precision of CBLs measured in different scales. Mathematically, these metrics are defined as follows, [7]:

$$MPE = \frac{100}{n} \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{\bar{y}} \qquad \textbf{(4)}$$

$$MAPE = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{\bar{y}} \right| ; \; nRMSE = \frac{\sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2}}{\bar{y}} \qquad (5)$$

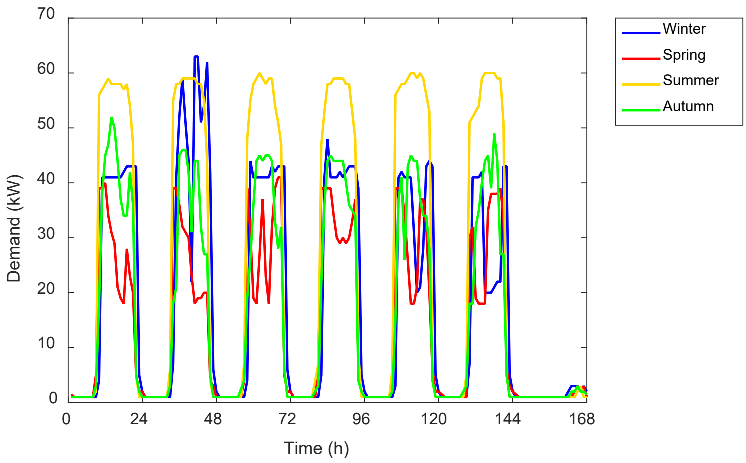
where y_i is the real demand at time i, $\hat{y}_i$ is the CBL (forecasted demand) at time *i*, and $\bar{y}$ is the mean of the real demand for the *n* values. Remark that *n* refers to the length of the DR evaluation period.

4. Results and Discussion

4.1. Case of study

To test and validate the methodologies for the calculation of CBLs described above, a representative commercial customer from the south-east of Spain has been selected. The reason for choosing this customer is that its high consumption and high share of weather-sensitive loads (mainly HVAC), compared to individual residential customers, makes them a target for their engagement in DR policies. At the same time, their management and aggregation are easy for SOs, as their consumption is "scheduled" and less variable than residential demand. Figure 4 presents the weekly demand for the different seasons of a year. As it can be seen, the hours of "start" and "end" consumption during a working day are always the same, but there is some variability during the day, mainly because of the weather. It is remarkable that in summer, the consumption is the highest as the HVAC is working all day because of the high ambient temperatures (average temp. max: 34ºC, min: 21ºC).

Figure 4. Weekly demand of a commercial customer on the four seasons of a year



4.2. Neural Network CBL developed

For the development of the NN and the performance of different tests, the program "MATLAB" is used. The input data is loaded with the format described for the years 2017 and 2018, performing the training, validation and verification of the NN with the output of the same years. Then, the NN is applied to the 2019 input data, evaluating the prediction output with real data for testing purposes.

The three methods discussed in Section 3.3 are used to train the NN. In these tests, a criterion is followed to consider that the training is finished: that a thousand epochs of calculation have been performed, that the mean squared error is too high (5.57e3) or 0, that the gradient between points is too high (1.47e4) or low (1e-7) or that the training time reaches twenty minutes. Some of the criteria are based on early stopping criteria to avoid excessive adjustment, stopping the execution in case of instability, or that the improvement with each epoch is not significant. The last condition is imposed in order to be suitable for use in one hour ahead forecasts for the electricity market.

The tables below (1-2) present the main results of the most significant tests. Although other networks with a higher number of layers and neurons have been tested, they do not yield significant results in an allowable computation time.

Table 1. Results of the NN training performance with 10 neurons/layer

		Train		Validation
Neural Network	**Algorithm**	**RMSE (kW)**	**Time (sec)**	**RMSE (kW)**
One-Layer NN	LM	10,05	2	10,21
	BR	10,00	10	10,08
	SCG	11,09	2	10,62
Two-Layers NN	LM	9,36	2	10,17
	BR	9,03	35	9,85
	SCG	**9,98**	**3**	**9,80**

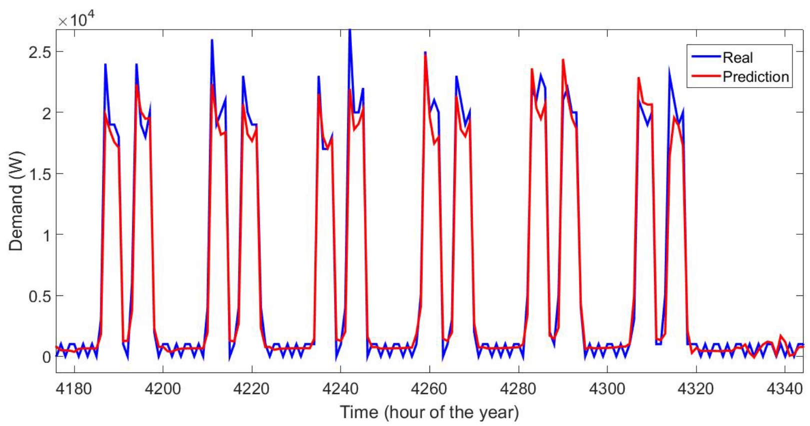
Three-Layers NN	LM	7,89	4	13,97
	BR	7,18	83	15,49
	SCG	9,88	3	13,39
Five-Layers NN	LM	8,58	4	13,35
	BR	5,61	145	16,19
	SCG	10,25	4	13,59

Table 2. Results of the NN training performance with 50 neurons/layer

		Train		Validation
Neural Network	**Algorithm**	**RMSE (kW)**	**Time (sec)**	**RMSE (kW)**
One-Layer NN	LM	8,95	4	10,22
	BR	8,66	71	10,54
	SCG	11,62	4	10,93
Two-Layers NN	LM	7,84	175	10,68
	BR	4,43	1200	14,16
	SCG	9,18	18	10,49
Three-Layers NN	LM	5,59	558	14,73
	BR	9,06	1200	13,17
	SCG	8,93	22	13,65
Five-Layers NN	LM	3,02	1200	17,04
	BR	15,72	1200	15,80
	SCG	8,8	45	14,03

After evaluating all the tests, Scaled Conjugate Gradient (SCG) is chosen as the most reliable method for training the network. Due to its reduced training time and its good performance compared to the other methods. Among the tested networks, the one formed by two layers with ten neurons each, is the one that returns the best results as shown in Table 1. Figure 5 shows the comparison of the CBL predicted with the NN selected and the real data.

Figure 5. Neural network prediction against real data



4.3. Comparison of unadjusted and neural network baselines

In this study, we have obtained CBLs for a commercial customer with six different methods, to compare the performance of each method. The methodologies analyzed are the High3of5, Low3of5, Mid4of6, Nearest5of10, Mid6of10-weigthed and the NN baseline selected in section 4.2.

Data from January 2017 to December 2019 was available for obtaining the CBLs. As the NN method needs a great database to train the net, data from 2017 and 2018 was used with this objective, and then, we have tested the methodology with the 2019 data. For comparison purposes, the other traditional methods were only evaluated in this period (year 2019). The CBLs have been calculated only for workdays and work hours, that is, the days and hours in which the commerce is opened (from Monday to Saturday and from 10 to 23h). That is because there is no possibility of applying DR policies when the commerce is closed, as the consumption is minimum. This can be appreciated in Figure 4 (hours 144 to 168, Sunday).

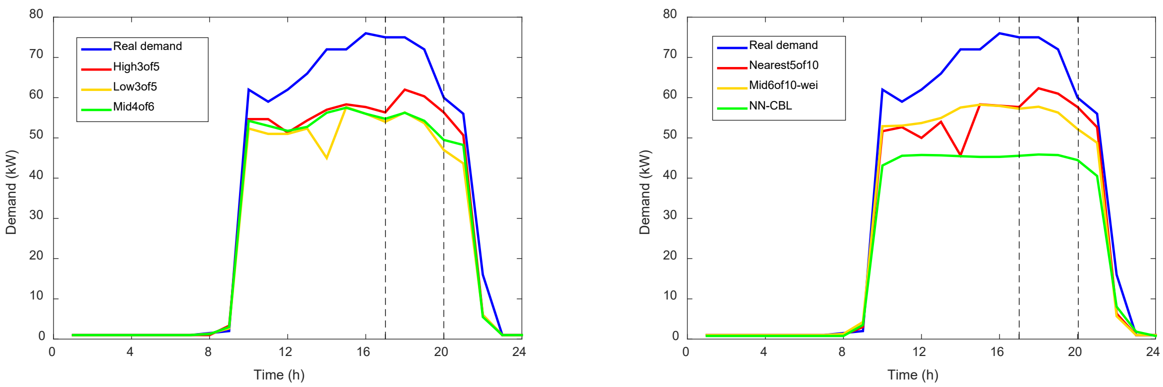
Table 3 presents the metrics for the different CBLs analysed. As it can be seen, the method with the lowest index of error is Nearest5of10, with a 12.38% of MAPE and a 17.78% of nRMSE. It is also remarkable that all the CBLs overestimate the demand, as in all methods, MPE has positive values.

Table 3. Error metrics of the unadjusted CBLs

CBL	MAPE (%)	MPE (%)	RMSE (kW)	nRMSE (%)
High3of5	15.55	8.79	6.04	21.00
Low3of5	12.78	0.61	5.96	19.86
Mid4of6	12.91	4.65	5.74	18.46
Nearest5of10	12.38	4.00	5.19	17.78
Mid6of10-weighted	14.49	5.35	5.81	19.93
NN-CBL	17.60	2.52	6.75	21.55

Figure 6 depicts the comparison of the different methodologies for one day. There is marked with dashed lines the period that is going to be used as DR event for the adjustment of the CBLs, i.e., from 17:00 to 20:00 (see next Section).

Figure 6. Comparison of unadjusted CBLs to real demand on a specific day



4.4 Adjusted baselines: WS, PBLM and backward coefficients

Sometimes, SOs use different adjustment coefficients to improve the performance of the CBLs. These coefficients are calculated with data from the consumption of the previous hours to the DR event. However, as the DR revenues are normally obtained after the event, there is also the possibility to use adjustment coefficients calculated with data from the hours after the event. In this paper, we have calculated two multiplicative pre-event (Weather Sensitive, WS and Physically Based, PBLM) and one post-event (backward, BW) adjustment coefficients. As it was explained in section 3.4, it can be necessary to consider two buffer periods for DR events to reduce the perturbations in the calculations of CBLs that could be caused by gaming, preheating or precooling strategies or also the normal increase of consumption after the event to compensate the demand reduction during the application of DR policies. This rise in consumption after a DR event is called "energy recovery period". In table 4 there are shown the definition of the adjustment coefficient and buffer periods applied.

Table 4. Definition of the adjustment coefficients for the CBLs analysed

Adjustment coefficient	Data	Period	Buffer
Weather sensitive (WS)	Pre-DR	First 2 hours of the 4-hour period pre-DR event	2 hours before event
Physically based (PBLM)	Pre-DR	Last 2 hours of the 4-hour period pre-DR event	No buffer
Backward (BW)	Post-DR	Last 2 hours of the 3-hour period post-DR event	1 hour post event

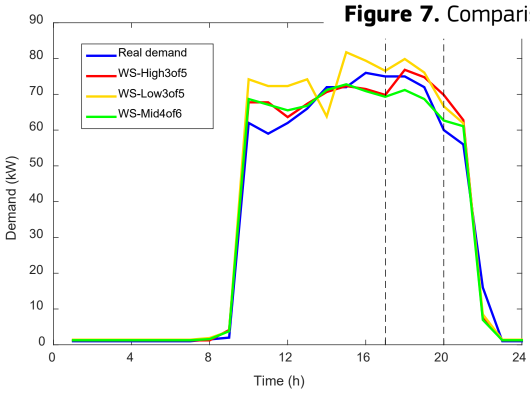
A DR event is defined during the working hours, in this case, an event that starts at 17:00 and ends at 20:00. According to the definitions of the table 4, the adjustment coefficients are calculated as follows:

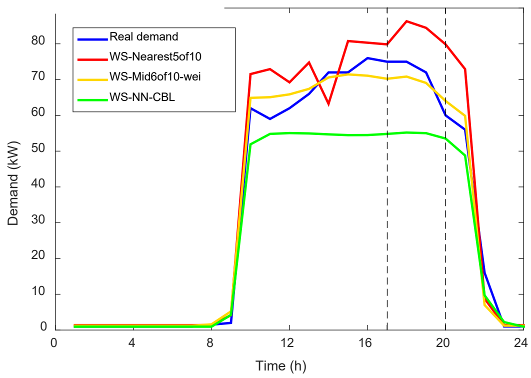
- The WS coefficient, commonly used by NYISO, is calculated with the data from the two first hours of the four-hour period before the start of the DR event, that is, from 13:00 to 15:00. In Table 5, there are shown the error metrics for the WS adjusted CBLs. As it can be appreciated, in all case, the error is reduced, e.g., MAPE is reduced from 17-12% of the unadjusted baselines to around 7% for the WS adjustment. Figure 7 shows the WS-adjusted CBLs for a specific day of 2019 compared to the real demand.

Table 5. Error metrics of adjusted WS-CBLs in DR period

CBL	MAPE (%)	MPE (%)	RMSE(kW)	nRMSE (%)
WS-High3of5	7.03	2.19	4.17	8.53
WS-Low3of5	7.36	0.85	4.44	8.94
WS-Mid4of6	6.99	1.94	4.18	8.48
WS-Nearest5of10	6.99	2.15	4.21	8.48
WS-Mid6of10-weighted	6.78	1.78	4.02	8.17
WS-NN-CBL	7.49	-0.10	4.51	9.00

Figure 7. Comparison of WS-CBLs to real



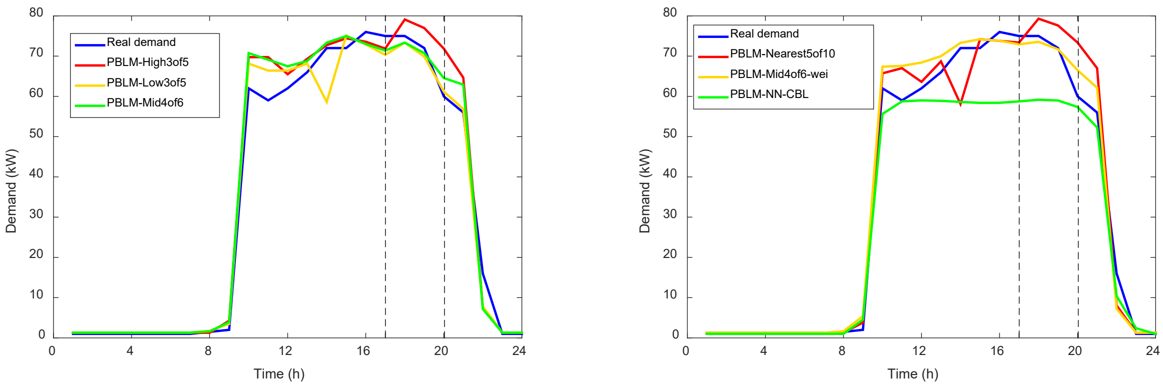


- The PBLM coefficient, defined by Physically Based Load Models [40], is calculated with data from the two hours before the start of the DR event, without any buffer, so the period used for the calculation is from 15:00 to 17:00. Table 6 present the performance of the PBLM adjusted CBLs. As in the WS adjustment, PBLM adjusted baselines reduce the error from their unadjusted versions. In addition, the PBLM adjustment coefficient slightly improves the performance compared to the WS coefficient (MAPE is reduced around 1.5-2%). Figure 8 present the different PBLM-adjusted CBLs compared to the real demand for a specific day.

Table 6. Error metrics of adjusted PBLM-CBLs in DR period

CBL	MAPE (%)	MPE (%)	RMSE(kW)	nRMSE (%)
PBLM-High3of5	5.09	2.20	3.16	6.32
PBLM-Low3of5	5.06	0.46	3.17	6.32
PBLM-Mid4of6	4.75	1.86	2.98	5.98
PBLM-Nearest5of10	4.72	1.53	2.94	5.90
PBLM-Mid6of10-weighted	4.78	1.78	4.03	5.93
PBLM-NN-CBL	6.08	1.25	3.68	7.50

Figure 8. Comparison of PBLM-CBLs to real demand on a specific day



- Finally, the BW coefficient, defined also by PBLM [40], uses data from the last two hours of the three-hour period after the end of the DR event, that is, use a one-hour buffer period post-event. Consequently, the BW adjustment coefficient is calculated from 21:00 to 23:00. In this case (Table 7), the BW adjusted CLBs reduce the error compared to the unadjusted ones, but their performance is worse than the other adjustment coefficient, except from the case of the NN-CBL, in which the BW-CBL is the most accurate.

Table 7. Error metrics of adjusted BW-CBLs in DR period

CBL	MAPE (%)	MPE (%)	RMSE(kW)	nRMSE (%)
BW-High3of5	11.23	2.27	3.11	10.11
BW-Low3of5	9.72	1.71	2.97	9.60
BW-Mid4of6	9.95	1.63	2.89	9.34
BW-Nearest5of10	10.06	1.74	2.90	9.30

BW-Mid6of10-weighted	9.77	2.07	2.84	9.18
BW-NN-CBL	4.24	-0.90	2.50	5.85

The reason for the rise of the error in this case can be the hours in which the BW coefficient is calculated. From 21:00 to 23:00 the commerce is closing, and the consumption is reduced, so the calculation of the adjustment could be more imprecise than the other ones. For this reason, it is necessary to analyze the convenience of each adjustment coefficient to the type of customer we are working on, as each coefficient can be more adequate for one customer but not for others, depending on its consumption routines and behaviours. Figure 9 shows the six different BW adjusted CBLs studied, compared to the real demand on a specific day.

Figure 9. Comparison of BW-CBLs to real demand on a specific day

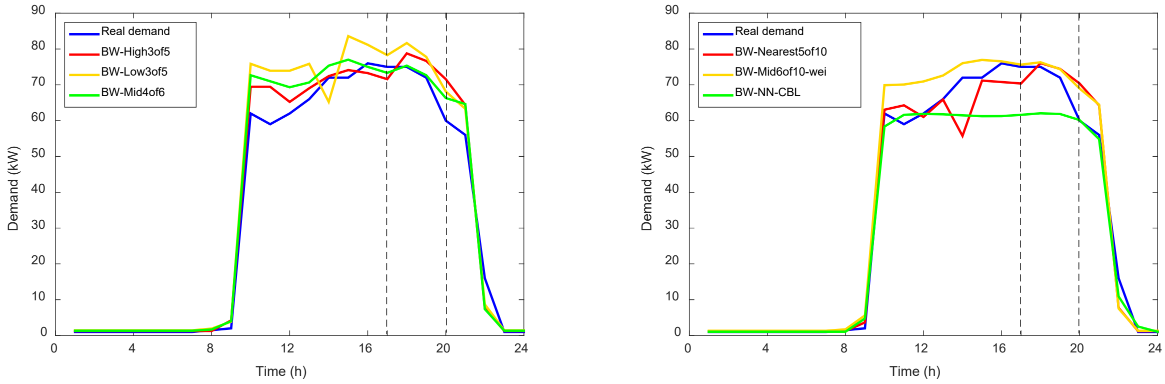
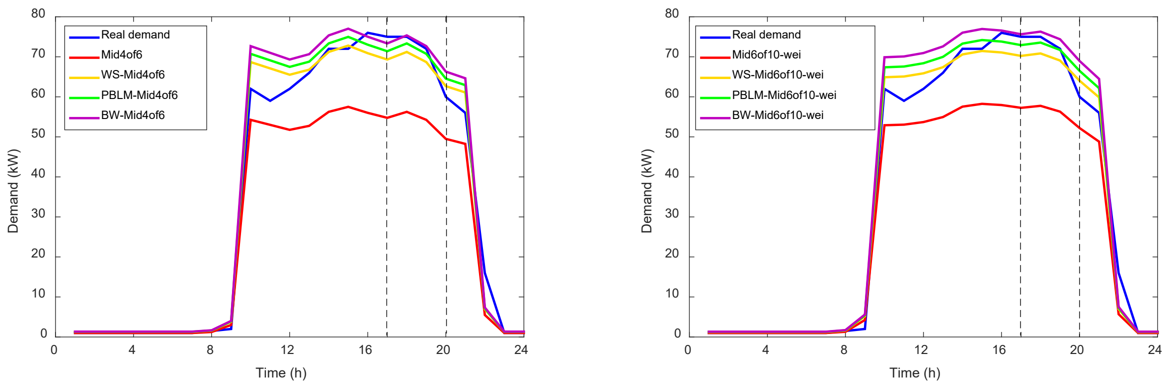


Figure 10 shows the Mid4of6 (8a) and the Mid6of10-weighted (8b) CBLs with all the adjustment coefficients presented in the paper, compared to the real demand (i.e., SM data), on a specific day. We can conclude that adjustment coefficients improve the performance of the unadjusted CBL, , as it can be appreciated in the Figure 10.

Figure 10. Unadjusted and adjusted CBLs compared to real demand on a specific day (a) Mid4of6 (b) Mid6of10-weighted



(a) (b)

5. Conclusions

The verification of demand flexibility becomes a key issue for the development of DR. Baselines are the basis to provide this verification, which defines the subsequent revenue and payment. An accurate CBL also emerges as catalyser for engaging new customers in markets recognizing and given credit for their real flexibility.

Moreover, demand resources from small and medium segment (an SME, in the case presented in this paper) need an accurate and fair verification of their response. In this proposal, the accuracy of demand forecasts with DR (using PBLM modelling to tune adjustment factors) is improved with respect to a simple base profile. Some other approaches involve specific and complex methodologies that have proven to define accurate CBLs. The main drawback of more complex proposals is that these options usually increase the complexity of DR and they sometimes require different models for different customers and segments. Moreover, some paper in the literature report that these kind models can present problems if DR performs periodically when the customer changes its behaviour, or simply if the aggregator develops more complex products (e.g., the participation of demand in several markets and services). Literature shows that base profile (unadjusted) CBLs are not the best option, but they can improve their performance through adjustment factors. Until now, these factors have been proposed based on experience. This paper highlights the convenience of using adjustment factors explained by PBLM in other segments, such as commercial SMEs, and that a double-adjusted CBL also displays an improvement in performance. Thus, the proposed methodology arises as an adequate, accurate, simple and understandable estimator, i.e., the main characteristics of a good CBL.

This paper also presents the synergies associated with the use of other tools used by aggregators, such as NIALM, customer segmentation and enabling technologies to verify load flexibility. In this case, the adjustment period can be justified and improved both before and after the period of DR events. In this way, different DR actors can obtain necessary feedback to perform a better evaluation of the DR potential, necessary for the customer-centred markets to be envisaged in the 2050 horizon.

Acknowledgements

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Methodologies and Proposals to Facilitate the Integration of Residential Consumers in Electricity Markets and Smart Grids

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Abstract

Future electricity networks need to be flexible on the demand-side to make more credible decarbonizing energy policies and, specially, the integration of renewable sources. Therefore, international trends establish that Power Systems will need more active consumers (some of them with small generation resources), will integrate some storage facility and should increase electrification, mainly in transportation end-uses. Some traditional barriers begin to break down; for instance, the consideration and remuneration of demand and generation resources (considering their capacities), but at the same time, new barriers arise, for instance the economic compensation for unbalances due to the activation of Demand Response. An active participation of customers and the demonstration of their real and future capabilities are important challenges for small and medium segments. The research network REDYD-2050 has been funded by Spanish Ministry of Science since 2015 and it integrates ten research groups in key technologies areas for the development of Distributed Energy Resources (DER). This paper presents the objectives of REDYD-2050, some of its works, points of view, and experiences with different problems dealing with load and storage modeling, aggregation, control and monitoring, enabling technologies, cybersecurity concerns, markets, or demand and generation forecasting. All these methodologies are important issues to integrate DER and propose innovative solutions, in new scenarios, both in the short and medium term.

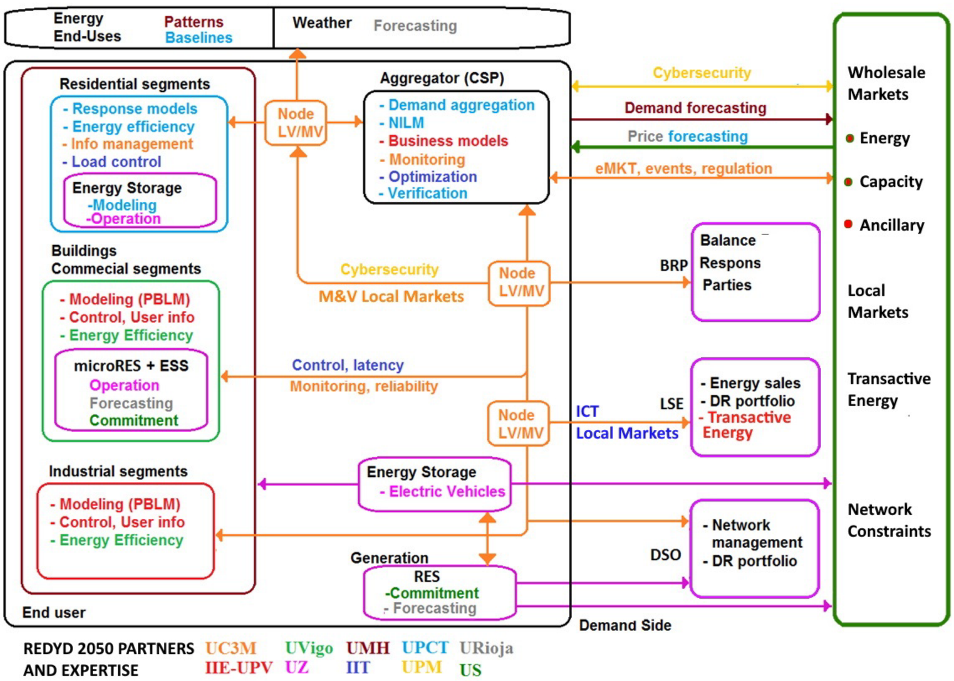
1 Introduction

The main purpose of REDYD-2050 research network is to exchange knowledge and experiences that will contribute to the development and deployment of DER in power systems. For this purpose, it is necessary to develop, revisit and improve methodologies that enable the evaluation and comparison of technical capacities of DER with respect to "conventional" supply-side resources. Also, it is important evaluate their cost-effectiveness in future markets [1] because different revenue (supply vs. demand) is a barrier of entry for new technologies. Opportunities for flexibility are also emerging beyond the conventional markets, for example Local Energy Markets (LEM [2]) and Local Energy Communities. Equality in revenue is another important issue but it must be based in the principle of equality in capabilities. These hypotheses must be demonstrated and verified for DER, and specially for Demand Response. It is important to note that revenue rules are changing in the last years for DR. For instance, the equality in revenue for DR has been established in the USA in 2011 but modified in 2020 [3]. Another example is the European Union (EU), where the implementation of some mechanisms such as the compensation from aggregators/consumers to energy suppliers for unbalance [1], during DR policies, can erase most or all the revenues currently available to aggregators and consumers, putting their associated potential benefits at risk. The so-called "Energy Union" is one of the thematic priorities for the European Commission (EC), where DER should play a key role in energy policies if the integration trend of RES aims to be credible. According to IEA reports [4], the share of RES in residential and service buildings in the EU increased around 24% in 2017. In this year, total renewable energy accounts for around 50 Mtoe (the direct use of RES for electricity and district heating in building). EC states [1] that the future electricity market should have at its core an active consumer taking advantage of new and enabling technologies to reduce their costs and allowing that customer fully participate in the energy transition. From the economic point of view, the potential of DER is relevant. For instance, benefits from 120 M€/year to 1440 M€/year in the EU (depending on the scenario being considered). Technically, DR could explain 24% of peak shavings in the most favorable and ideal forecast [5].

On the other side, small and medium consumer segments explain for more than 50% of consumption of EU-27 [6], so their contribution in new markets and services is of the highest economic interest. But customers need demonstrators, pilots, and in-depth exploration of their possibilities. The development of DER in these segments is complex and includes the linkage amongst many different problems (figure 1): the need for aggregation and third parties; the deployment of Information and Communication Technologies (ICT) and the capital cost efficient loads; the complexity of markets; the lack of experience or pilots (e.g., in local markets); lots of barriers (legislative, education, minimum aggregation levels); complexity of products and markets, or the volatility and scarcity of cost and revenues.

Some risks exist and the prove is that previsions with respect to DR participation have failed in last decades and can fail in the near future. For example, and according to the US Energy Information Administration, DR programs have a potential to reduce around 31 GW in the US Electric Power System (2019), but only 11.3 GW were deployed [26]. Another example, some EU research projects state that energy authorities (for instance, in France, a very active country in DR in the last decade) have recently proposed a downward adjustment in their flexibility forecasts. Specifically, from 6GW in 2023 to 4.5 GW. According to some European Reports from professional associations, we are not yet where we need to be to fully exploit the benefits of DER [27]. In conclusion, new and improved solutions are needed to change these trends in the future.

Figure 1. REDYD2050 overview of DER issues, framework, interconnections, tasks, and expertise of the consortium by team (team acronyms: UC3M: U. Carlos III; UMH: U. de Elche; IIT; Comillas Pontifical; US: U. de Sevilla; UPM: U. Politécnica de Madrid; IIE-UPV; Institute for Energy Engineering; UZ: U. de Zaragoza; UPCT: U. Cartagena; URioja: U. de La Rioja; UVigo: U. de Vigo). http://www.demandresponse.eu



Main REDYD-2050 contributions and future developments in some of these DER areas depicted in figure 1. It represents the interaction between some of the tools being used by the different agents involved in DER: customers, aggregators, marketers, Curtailment Service Providers (CSP), Local Serving Entities (LSE), Balance Responsible Parties (BRP) or Distribution Systems Operators (DSO). A main concern is that small and medium customer need a minimum threshold to participate in markets and services (from 50kW to 1MW according to different rules of each market or country). This can be done through aggregation. First, the evaluation and deployment of DR potential need some elemental models (PBLM, left side in figure 1) and further aggregation procedures to simulate the aggregated response (houses, buildings…). In this way, the aggregator of demand is able determine the potential of resources (e.g., minimum reduction levels, loss of load service, energy recovery…). As DR is usually achieved by Thermostatically Controlled Loads (TCL) with some kind of storage (explicit or implicit, i.e., the walls of the dwellings or a heat reservoir), aggregators need some tools to perform DR simulations before the event or response is due to guarantee that customer service remains above some limits (e.g., indoor or water temperature).

Another important aspect is the necessary linkage between tools and methodologies. For example, Non-Intrusive Load Monitoring (NILM) applied to Smart Meter (SM) data to tune the parameters of each PBLM model.

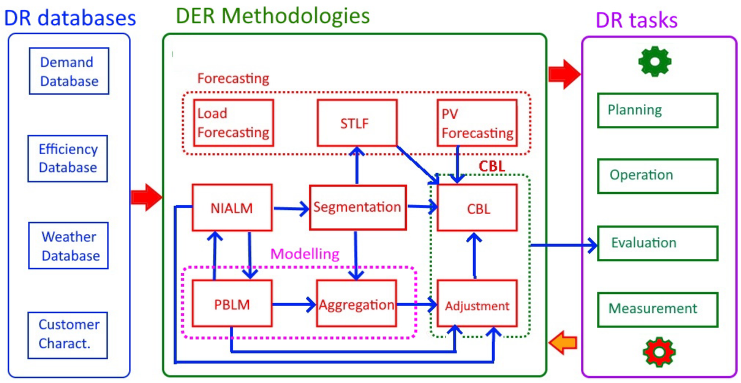
But at the present aggregation is a problem that encompasses more resources than load. Prosumers increase their share in distribution systems and include storage and generation which changes net demand (left side of figure 1). Then, it is necessary to consider homogeneous and heterogeneous groups of loads and storage resources. Another use of NILM is to help in the development of average end-use patterns (i.e., the so-called Customer Baseline Load, CBL) from smart meters' measurements. Another example of synergy between methodologies is the participation in energy markets (right side of figure 1). The aggregator needs load forecasts to define the energy requirements in day-ahead markets and avoid penalties in balance markets, but also price forecast to evaluate the potential of implicit DR through economic models for DER.

The rest of the paper is organized as follows. Section 2 deals with overall DER issues and the main tools necessary for their management: grey/white boxes for modelling, the integration of demand with renewable sources and the improvement of balance between both resources, the certification of demand response (Customer Baseline Loads, CBL), RES forecasting and Local Energy Markets (LEM). Section 3 discusses some barriers, challenges and trends for DER and the role of Information and Communication Technologies to overcome them. Finally, in Section 4, some conclusions are stated.

2 DER and Active Customers

The complexity of tools and methodologies being used to solve DER issues, and especially the specificity of those tools for a customer or problem, can become a barrier for small and medium customers, including their aggregators. A main idea of REDYD is the interconnection and linkage between DER tools, and the use of a core of tools and methodologies to solve different problems. An example is depicted in figure 2.

Figure 2. Linkage among DER methodologies (adapted from [15] as a conclusion from previous REDYD research results). The example shows the methodologies involved for the improvement of conventional CBL approaches explained later in the paragraph 2.4).



Next paragraphs present some examples and solutions proposed by REDYD for some DER issues, in different research works, as well as new proposals for research development in the future [8].

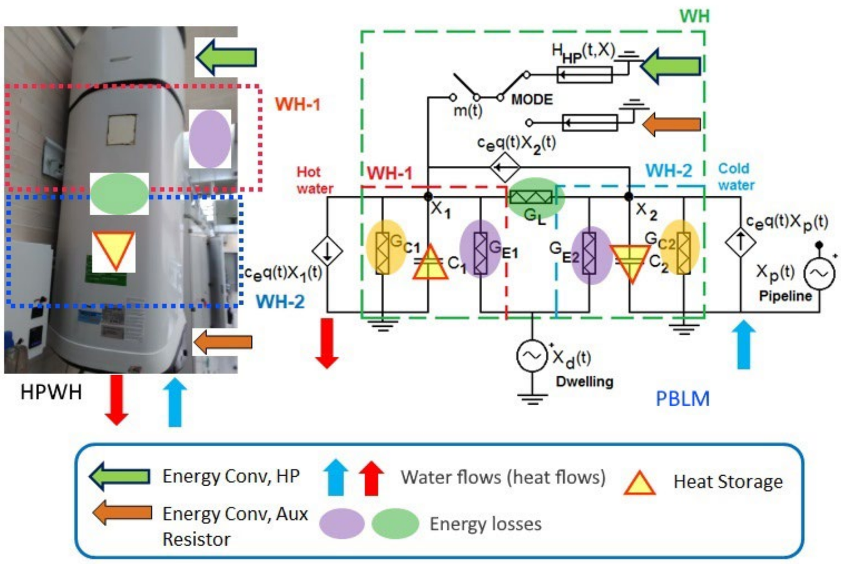
2.1 Characterization and Aggregation of DER

It is important to consider that markets should not be unnecessarily complex to understand (from the point of view of small/medium customers) and that customers and their aggregators can access to complex products in many power systems. Moreover, it is recommended in the EU [7] that the barriers for entering multiple markets must be lowered, to help the so called "stack value" across markets. For these reasons, it seems necessary to use flexible and "simple" tools to characterize and aggregate DER, after, before and during events.

For this issue, the proposal of REDYD2050 team is the use of Physical-Based Load Models (PBLM, [8]), i.e., grey-box models. The core and interest of these models are that they intend to explain and reflect the physical phenomena occurring on the loads and their environment through simplified thermal-electrical analogies. In this way, the same model (or a similar one) can be fitted and committed to develop several tasks. Thanks to this "all terrain" performance of PBLM, different commitments for energy balance, ancillary services, energy markets, or capacity markets, in simple and complex products, can be developed, as it was proposed in [9].

Figure 3 depicts an example of this methodology for Water Heaters (WH). First, an elemental model is proposed based in the physical knowledge of the load. The hot water reservoir, i.e., the capacity of energy storage, is modelled through two capacitors (C1 & C2) in the equivalent model. The split of the reservoir during modelling tasks and these two capacitors are needed to represent the stratification of hot/warm/cold water during the periods of use of the load, mainly during water draws. This is important depending on the use of the model and the timeline and speed of response. Besides, energy conversion is represented by two current sources (for the heat pump, H_{HP}, and the auxiliary resistor). The control is performed by a switch that can change the operation (single or dual heat sources) of the real load. It is also necessary to consider the service the customer obtains from this load (hot water flow q(t) at X_1 temperature). For this reason, the model evaluates (or previously simulates) this temperature to avoid any potential risk of customer discomfort during a control. All these parameters can be estimated with Artificial Intelligence (AI) methodologies, for example Genetic Algorithms from submetering devices database or from Non-Intrusive Automated Load Monitoring methodologies (NIALM) in real situations (this feedback from different DER methodologies has been depicted in figure 2).

Figure 3. Electrical-Thermal equivalent of Heat Pump Water Heather (HPWH): appliance and physical processes being modelled.



The model can be mathematically represented by a state-space system, such as the system presented in equation (1).

$$\begin{pmatrix} DX_1(t) \\ DX_2(t) \end{pmatrix} = \begin{bmatrix} -\frac{G_L + G_{C1} + G_{E1} + c_e q(t)}{C_1} & \frac{1}{C_1} G_L \\ \frac{1}{C_2} G_L & -\frac{G_L + G_{C2} + G_{E2}}{C_2} \end{bmatrix} \begin{pmatrix} X_1(t) \\ X_2(t) \end{pmatrix} + \begin{bmatrix} \frac{1}{C_1} G_{e1} & 0 & \frac{1}{C_1} \\ \frac{1}{C_2} G_{e2} & \frac{c_e q(t)}{C_2} & 0 \end{bmatrix} \begin{pmatrix} X_d(t) \\ X_p(t) \\ H_{HP}(t) \end{pmatrix} \quad (1)$$

Eigenvalues obtained from this system allow the aggregator to obtain the different dynamics during the load transient state and determine the necessary changes in the model (reductions/refinements) and the horizon of response of the load (i.e., demand reduction vs. load service) to refine the model (i.e., the increase or decrease of state-space system order). According to these values, specific markets and services can be selected as a suitable target for DR through the load. Moreover, those eigenvalues enable the definition of criteria for the aggregation of different loads into the same end-use (i.e., homogeneous and heterogeneous control groups, depending on minimum levels of required for response in each power system, from 50 kW to 1MW [23]) and different end-uses to guarantee a fast or coherent response of load group in complex scenarios (e.g., in several markets and services). The aggregation can be obtained from several methodologies: from MonteCarlo to Probabilistic Partial Differential Equations. Some examples are provided in REDYD2050 publications web page [8].

It must be considered that other DER resources could be managed out of load. This is a core issue for REDYD2050 research groups in the future horizon 2050. The consideration of service variables (e.g., the temperature of hot water X1, figure 3, the state of charge of water reservoir…) makes possible to check the availability of each DER resource to participate in different markets: balance (through storage) and frequency services (energy conversion through HP compressors and auxiliary resistors) without a significant loss of load service (in the case of figure 3, a minimum temperature to water drawn q(t) is set to fix control).

2.2 RES Forecasting

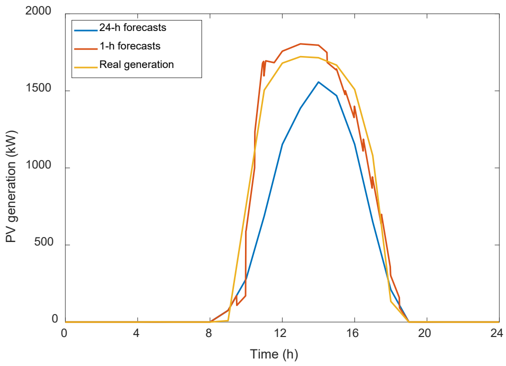
Short-term forecast of power generation in small-scale plants based on RES integrated in grids (medium and low voltage) is essential to enable a successful participation of small and medium consumers in electricity markets and smart grids. In this context, special focus has been placed on photovoltaic (PV) power generation forecast, since PV systems are the RES based generation with higher global capacity annual growth in the last three years [10], and a significant part of these systems is integrated right next to residential consumers.

The development of PV generation forecasting models has followed a parallel path to the development of load or wind power forecasting models. Models based on time-series approaches, regression techniques or machine-learning methods have been widely described in the literature in recent years. In general, short-term forecasting models of PV power generation, due to the volatility of the solar resource, present relatively greater forecasting errors than load forecast models for a same time scale. Furthermore, the performance of PV power forecasting models is site-dependent, i.e. models developed for a particular PV plant may give very different performance when applied to plants in locations with different climatic conditions.

Short-term PV power forecasting models (up to 48 hours in advance) need a set of explanatory variables including weather forecasts obtained with numerical weather prediction tools. These weather forecasts correspond to global horizontal irradiance, temperature, wind speed at a few meters above the ground surface and cloud cover, all with the desired spatio-temporal resolution. Although these models give the best forecasting results for horizons above a few hours, for smaller horizons (minutes to a few hours) persistence models can offer better results. The persistence model [11] assumes that the clear-sky index (relation between measured power output from a PV system and the simulated power output under clear-sky conditions) remains constant.

Our works, within the REDYD-2050 network, has been aimed not at developing new short-term forecasting techniques, but at illustrating how combined load and PV generation forecasts can be useful for the proposal of efficient DR strategies, and how DR actions can damper the forecast errors due to both combined models [12]. We have also found that simple error adjustment techniques can substantially improve the forecasting performance for 1-2 hours horizons using the PV power forecasts obtained the previous day. Figure 4 depicts the achieved improvement. An adjustment coefficient based on the ratio between measurements in the present day (i.e., the four PV actual data during the previous hour) and outputs from the 24h PV forecast model. The adjustment achieves a noticeable gain in the accuracy of the forecast.

Figure 4. Comparison between real data, 24h forecast and very-short term PV forecast achieved by REDYD adjustment method

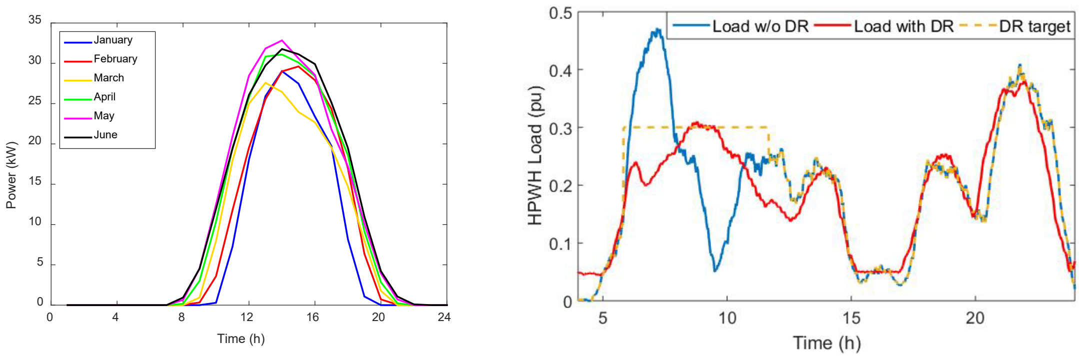


In the near future, our research works will be focused on the development of PV power generation probabilistic forecasting models, i.e., models that include information related to the uncertainty in the forecast, and their integration in decision-making processes related with DR actions and consumers' participation in electricity markets.

2.3. Integration of loads and renewable sources

Four ways of using demand flexible-load resources with some kind of energy storage can be found in papers and technical reports: peak saving, energy storage, fast response and energy efficiency. Some of them have been reported by REDYD research groups [9]. Usually, ways of using DER are centered in Power System problems but as stated before, engineers should focus their effort on new customers, and specifically in prosumers. For instance, some other authors have presented [24] an elemental and an aggregated model for the Australian Power System that intend to switch controllable demand from low to high renewable sources periods and make more profitable RES in small and medium users, independently of power system peaks. Following the example presented in subsection 2.1, HP Water Heaters have been selected again to show the capabilities of an aggregated model to explain changes of demand and follow small renewable PV generation (e.g., figure 5a). Figure 5b depicts the demand of HPWH aggregated load (blue line) without control committed to follow low price periods (ToU, dynamic tariffs or energy market prices). The planned target (orange line) intends to change demand from early morning to morning-afternoon period to take profit or store the peak of RES capacity of generation. The result of PBLM simulation is also shown in figure 5b. It demonstrates the possibilities and flexibility of this kind of loads, the possibility of interaction between DER, and the success of this flexibility to take the maximum profit from PV potential enabling the engagement of new consumers and, especially, prosumers in DER portfolio.

Figure 5. RES commissioning of Heat Pump Water Heater aggregated load: a) Average profile for a PV generation unit (40 kWp) installed in the south-east of Spain (panels are fixed facing south and tilted an angle of 30º); b) Simulation of HPWH management to balance a change of the peak of these loads from 7 h to 8-10h (orange dashed line) while these loads keep their service (i.e., hot water demand q(t), see figure 2) for their customers.



a b

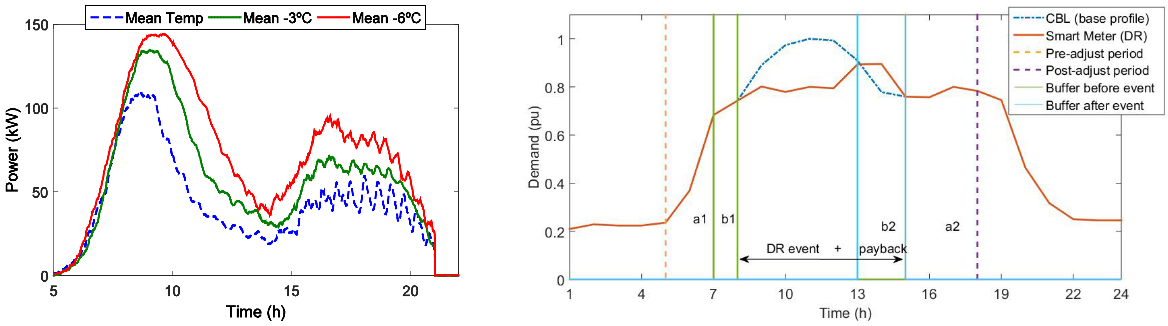
2.4 Certification and Validation: Baselines

Problems in the evaluation of revenue and the measurement of energy flows may arise when a customer has several and different contracts; one with the retailer and another with an aggregator (providing response to explicit DR in several services or markets) [7]. Those contracts can involve economic compensations and revenues (see for example article 17 of the European Directive 2019/944 [1]) that affect the viability of new DER resources because the potential decreasing of revenues. Certification and qualification of DER sometimes presents the same problem. There is a need to evaluate and justify an amount of flexibility to be achieved through DER that cannot be measured outside lab scenarios. These issues require the use of a simple and understandable Customer Baseline Load (CBL) methodology. The lack of appropriate CBL is reported as a barrier for customer access to markets [7]. Usually, these CBL are not standardized or accurate enough for all customers and products and, sometimes, ad hoc methodologies must be developed for a specific customer, power system or country, for instance through regression methods, neural networks or machine learning that become more and more complex while accounting for all DR possibilities. In other cases, the effort to obtain this methodology is too high and makes more difficult the penetration of DER, especially when the aggregation of small resources is needed.

The proposed idea of REDYD2050 team is to use a well-known and stated CBL approach, for example the evaluation of X past data in a period Y (e.g., HighXofY, MidXofY, NearestXofY methods) [13] as the base profile for CBL, but changing the usual adjustment coefficients applied to improve the performance of CBL, that are refined through the information provided by PBLM simulation (i.e., a model also used for the evaluation and aggregation of DER, see paragraph 2.1) as it is shown in figure 2. This approach makes more understandable the baseline and could help in the classification of gaming with respect to a justified change of load dynamics due to weather. A detailed example has been developed in a companion EEDAL22 paper (paper #84) for a commercial customer (peak load, 80kW), but other previous examples developed by REDYD 2050 cover examples from university buildings (peak load, 500kW) and industrial customers (peak load, 650kW) can be found in [14], [15] and demonstrate the potential and possibilities of the proposed methodology.

The justification of the method is discussed through a simplified example. Let us consider, for instance, the CBL in NYISO EDRP reliability programs. The adjustment factor is obtained by means of the first two hours of the four-hour period prior to the commencement of the reliability event. Figure 5a presents the behaviour of a homogeneous group of Heat Pump (HP) loads obtained through PBLM simulation. For these loads, and for some control periods, the period for this adjustment can be wrong. For example (figure 6.a), from 5 to 7 am the demand is the same, irrespective of changes in weather, whereas from 7 to 9 am the dependency of demand vs. weather is evident. This is due to high coincidence in "on periods" from 5 to 7 am because all loads start their duties at the beginning of the weekday. Before to plan some management of the load, the aggregator can perform a specific simulation, and he can obtain, for a defined event period (see for example, figure 6b), the right periods to adjust CBL (Pre-adjust and Post-adjust, in the same figure 6b). The aggregator can justify the load behavior within the DSO or TSO, and jointly can agree, and define, the periods forbidden to choose an adjustment coefficient (the so-called buffer periods in figure 6b). In this case, REDYD also proposed a backward adjustment for the estimation of payback (buyback/rebound) period after control [14]. In this way, a double adjustment is proposed: before DR event to evaluate flexibility, and after DR event to assess energy recovery or “buyback”, an important concern for aggregators, LCE and BRP, for balancing purposes and compensations between aggregator and supplier BRPs.

Figure 6. CBL proposal: (a) Simulation of HP aggregated demand for a building at three different external temperatures during winter; (b) Adjustment and buffers periods for a DR policy and period.



a b

Table 1 summarizes some results with this methodology for three different segments: a commercial customer (SME), a university building and an industrial customer (meat sector). Table 1 compares the performance of some specific CBL approaches developed for a specific customer, the adjustment of these approaches with a “weather sensitive adjustment factor (WS) according [13], and REDYD2050 method (a base profile HighXofY, MidXofY and an adjustment coefficients based on PBLM to consider weather sensitivity of loads with double -forward and backward- adjustments, WS-PBLM).

Table 1. Evaluation of MAPE error (average event-days) for different CBL base profile and CBL with an adjustment method (WS: weather sensitive, WS-PBLM: double adjustment with PBLM).

CBL methodology		**Commercial customer (EEDAL22, paper 84). MAPE**	**University Building [14]. MAPE**	**Industrial customer [15]. MAPE**
Adjustment	**Base Profile**			
-	Mid6of10	14,49	-	-
-	High3of5	15,55	-	-
-	Neural Network	15,60	-	-
WS	Mid6of10	6,78	-	-
WS	Neural Network	7,09	-	-
WS-PBLM	Mid6of10	**4,78**	-	-
WS-PBLM	High3of5	5,09	-	-
-	Mid4of6	-	-	11,6
-	High5of10	-	-	13,5

-	Random forest	-	-	10,9
WS	Mid4of6	-	-	9,8
WS	Random forest	-	-	9,1
WS-PBLM	Mid4of6	-	-	**5,6**
WS-PBLM	Random forest	-	-	6,1
-	High5of10	-	10,32	-
WS	High5of10	-	4,92	-
WS-PBLM	High5of10	-	**3,87**	-

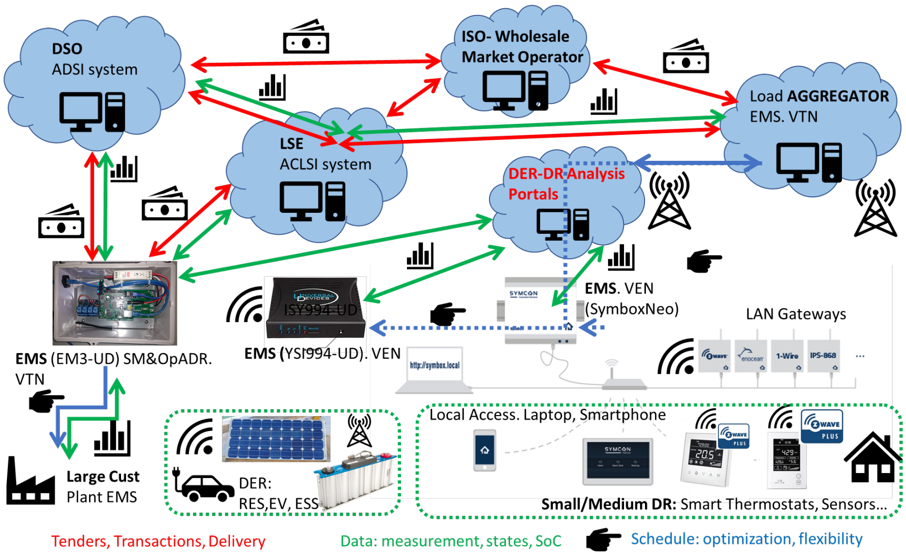
The main conclusion from this table is that "traditional" or "simple" baselines (HighXofY and MidXofY for these examples) reasonably estimate a wide range of customers on average DR event days, but the "traditional" methods are not the most accurate for single customers on individual event days (the table shows average values). More complex and specific baselines (Neural Networks or Random Forest, for instance) sometimes provide marginal improvements in accuracy but with a higher computational cost. PBLM adjustment enables an equilibrium between complexity and accuracy using the same core or tools for DER issues (figure 2) which is interesting for the increase of DER penetration in electricity markets and systems.

2.5. Local Markets and Services

New concepts and revenue opportunities appear for customers and, consequently, for the deployment of additional DER. For instance, local energy markets (LEM) and transactive energy (TE) [2] but they are still in development as pilots for segments of small and medium prosumers [28]. The wholesale price of electricity in several European Countries, including Spain, has risen from €40-50/MWh to €200-400/MWh in few months, including high volatility in price patterns. This increase of the price of MWh in conventional markets enhances other ways to develop and evaluate new forms of energy offers and bids. These new markets enable the customer participation in new flexible services. Some examples of "new policies" are sustainable peak management, export service management or secure DSO constraints. Notice periods for the customer can change from 30 minutes to 12 hours, and revenue can reach €1200 per MWh [28], which is interesting for the customer because benefits overweigh cost of participation. Of course, the complexity increases with a higher revenue.

The design and development of a market environment where energy transactions and operation services could be traded at local level appears as a real alternative. It will require to develop new mechanisms for the provision of services to and from prosumers to guarantee appropriate and sustainable benefits to allow the natural growing of renewables by 2050. These ideas have been grouped in the concept of "Transactive Energy". An automated energy transactions and management of DER must be developed soon. Devices such as air conditioners, water heaters, HPWH, EV, electric and thermal storage and generation would interact with aggregators, LSE, DSO, TSO and ISO. A simplified schema is depicted in figure 4, according to results presented in representative pilot experiences [2]. Home automation systems [25] have been used for REDYD2050 demonstrators showing a high performance for control and measurement [8] at an affordable cost by customers and aggregators. Other systems such as EM3 and YSI994 by Universal Devices [16] facilitate the development of the "Transactive Energy" (VTN nodes) and an effective engagement of customer. It also opens interesting possibilities for local markets, considering other methodologies developed for wholesale markets, such as PBLM, aggregation, NILM…, see figure 2. Efforts in the development of standards is also a cornerstone for this deployment of local markets (e.g., OpenADR2.0). Moreover, "enabling technology" such as EMS, SM, gateways, sensors, or actuators are the core for other DER tasks (for example resource modelling, validation, testing of DER, CBL definition, proposed by REDYD2050 teams, figure 2). Figure 7 depicts and schema for a potential development of transactive energy considering the experience in several research projects [8] and the developments of some pilots in the US power systems [2].

Figure 7. REDYD2050 proposed schema for Transactive Energy in the EU



The integration of enabling technologies, DER and customer opportunities through LEM requires an upgrading of the SmartGrid conceptual design as proposed in [17] to warrant the transparency, security, and integrity of the transactions.

3 Barriers, Challenges and Trends for ICTs

3.1. The role of ICT in DER scenarios

Information and Communication Technologies play a key role in Distributed Energy Resources scenarios. Communications architectures, technologies, and protocols, as well as Artificial Intelligence algorithms, Big Data tools, and Cloud Computing platforms need to be carefully selected to allow monitoring and controlling consumption, generation, and storage (including Electric Vehicles) in almost real time.

Once ICT solutions have been tested in medium to large demonstrators, the next challenge is to assess how well such solutions scale (since they will be eventually deployed at medium and low voltage level) and if they can be replicated in different scenarios without incurring in huge investments. As a result, SRA (Scalability and Replicability Analysis) of ICT solutions for Smart Grids scenarios with high penetration of DER are winning momentum right now, leveraging on simulation tools as a cost and time effective mean to achieve the previously mentioned goal.

As a matter of fact, part of the REDYD team has participated in the definition and evaluation of the methodology proposed in the H2020 project INTEGRID [18] for this purpose and is currently leading the ICT SRA in the H2020 project RESPONSE [19]. Notably, the INTEGRID proposal is based on a two-stage approach: first, a qualitative analysis, mapping the infrastructure under study onto the SGAM (Smart Grid Architectural Model), is carried out to identify potential bottlenecks; second, such potential bottlenecks are quantitively evaluated by means of simulations to determine their limits [20].

In addition, to achieve the flexibility required in foreseen scenarios, the DSO-TSO coordination is essential. ICT also play an important role to allow such a coordination – in some cases – in almost real time. Part of the REDYD team is also participating in the definition of ICT architectures for DSO-TSO coordination within the scope of the H2020 COORDINET [21] and OneNet projects.

3.2. Cybersecurity concerns

ICT brings many benefits, but it also entails risks, specifically related to cybersecurity. The monitorization and control of the whole electrical infrastructure, including the low voltage level, under the IoT paradigm increases dramatically the volume of nodes with connectivity, and so the attack surface, exposing such a critical infrastructure more than ever.

Dynamic risk analysis and management methodologies and tools stands out in this scenario as a cornerstone not only to guide investments, but also to assess the risk level of the infrastructure continuously and in almost real time. However, such risk analysis resources are inherited from the IT world, where they were developed and have been extensively used, and need to be adapted to the OT/IoT scenarios of a critical infrastructure such as the Smart Grid. These scenarios require holistic approaches, which involve proactive and dynamic cybersecurity methodologies and tools that allow identifying and responding quickly to threats that affect devices, technologies, protocols, and communications networks, as well as processes, applications, and the data they manage. The challenge now is the design of methodologies that consider the specific processes and dynamicity related to the OT systems, as well as the classical IT world.

In this context, part of the REDYD team has extensive experience researching in dynamic risk analysis and management systems [22] through several research projects. The current challenge includes the extension of this analysis to the OT scope, and the provision of and integrated cybersecurity awareness capability to the different levels of an OT management team. The work in the REDYD network is allowing to identify the specific cybersecurity requirements in the area of the DER scenarios, and how these requirements can be fulfilled in an IT/OT cybersecurity convergence approach.

4 Conclusions

Active consumer participation in electricity networks and markets is of the highest interest in the EU for the development of the new internal electricity market and the decarbonization of the energy mix, especially when conventional markets and power systems are stressed. The existence of formal barriers for small and medium customers, the aggregation levels and, the complexity of the problem for these users, makes it essential to share and discuss experiences amongst researchers from different academic disciplines, consumers and, in general, agents and operators of networks and markets. The sharing of experiences within the framework of REDYD-2050 platform, and the dissemination of its activities can contribute to improvements in the operation and planning of DER into the future Power Systems. The search of synergies between different research areas must be done to make possible energy objectives by 2050. REDYD is an example of this effort in the framework of R&D plans in Spain.

This paper has presented different methodologies and tools, and a general philosophy and framework, that consider the necessary linkage between the different problems and issues in DR and DER, rather than a continuous effort to develop specific tools with a low impact in the overall system. It has been shown that the integration of methodologies can achieve a positive benefit for the development of DER in the energy scenario in 2050, especially complex and plenty of barriers for small and medium customers. It seems necessary to develop more standard tools to avoid complexity and reduce methodological efforts in the deployment of DER, and some examples have been presented for modelling, measurement and verification issues. Also, it must be demonstrated that DER can develop a flexibility comparable to traditional supply-side resources, and physical approaches such as PBLM can help in the achievement of this objective. Moreover, these tools need be more understandable, flexible (grey boxes) and less complex to boost the effective engagement of customers and aggregators in DER portfolio. Finally, enabling technologies (ICT) play a main role for the management and to provide some feedback to the evaluation of modelling and the development and refining of new evaluation method and tools.

5 Acknowledgement

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Signal oriented building energy management system utilizing genetic algorithms for optimized battery operation and load scheduling

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Abstract

The increasing share of renewable energies in today's electrical power systems challenges the operation of a both emission-free and reliable energy supply. To handle fluctuations in power generation, current policies focus on grid expansion and flexible scheduling of generation capacities. However, the grid smoothing potentials provided by flexible demand must be taken into consideration, with a special focus on the increasing number of residential "prosumers". In this paper, a user friendly, grid-signal oriented operation of a prosumer system is investigated by optimizing battery utilization and the time-dependent scheduling of flexible loads.

The system is modelled via time series of both solar yield and electrical demand, where the latter is seen as a combination of a fixed baseload and a schedulable, flexible load. To create a reference, the total load is applied without any optimization, and the battery directly compensates occurring power lacks and excesses. Subsequently, an optimized battery operation has been achieved by the implementation of an improved genetic algorithm that schedules battery operation and minimizes grid interaction. Furthermore, the optimized flexible load schedule was calculated by another genetic algorithm. Despite limitations arising from the residents demands and technical restrictions, the approach adapts the system's operation well to a non-linear and non-steady grid signal. Combining both sub-optimizations, a significant reduction of the carbon footprint, represented by a dedicated cost function, and thus a grid supportive operation can be achieved without neglecting the residents' requirements.

Promising an active participation in future distribution grids, the implementation of a deep-learning-based regression model for the system's internal baseload prediction will be part of subsequent work as well as the adaptation to "real-world conditions".

Introduction

The transition of the energy sector towards a carbon neutral supply system shows its complexity in current electrical grid issues in Germany. The promotion of renewable energies results in a decentralized producer landscape with an increasing share of fluctuating power sources. Regarding the increasing overall demand, this new grid topology causes complex and critical situations in terms of voltage and frequency stability, demanding redispatching of generation resources.[1] To maintain a stable and reliable power supply, the current policy Redispatch 2.0 requires distribution grid operators (DSOs), transmission grid operators (TSOs) and plant operators to orchestrate the common power generation with respect to upcoming meteorological conditions and demand profiles.[2] Thus, transmission losses, asset overloads and curtailment of renewables shall be reduced to a minimum. But the operation of conventional power plants, supplying the so-called residual load, still is crucial for supplying the demanded energy. In this context, grid energy storage systems like classic pump hydro storages, batteries or power-to-gas solutions are essential technologies for smoothing fluctuating generation without high dependencies on conventional energy sources.[3] However, a stable power supply consisting only of renewables and storage units will require a significant extension of both generation and storage. With respect to the urgency of change, it is inevitable to expand the unilateral grid regulation of controlled generation to a bilateral approach with both flexible generation and demand, mediated by a significantly increasing storage capacity. Therefore, the growing number of "prosumers" might play a central role to adapt the demand on the low-voltage level to the capacity of the distribution grid.

Consisting of an electricity system with both generation (e.g. a solar generator) and a storage system (e.g. a battery), a monitored prosumer ("**pro**ducing con**sumer**") [4] provides a significant potential of adapting its grid interaction to applicable ecological and grid requirements.[5] Hence, prosumer applications are not only able to increase carbon-neutral electricity generation by keeping the residual load low, but could also have a significant impact on the necessity of future grid expansions, reducing them down to 61%.[6] Therefore, former pilot projects investigated the quantification and practical implementation of distribution grid flexibilities and developed a communicational framework between flexibility and DSO.[7] This enabled a local grid smoothing and thus helped to reduce the power compensation demand. Furthermore, the quantification of applied flexibility allows the device owners to be compensated for their ancillary service provision. Enhancing the impact of controlled flexibilities by integrating multiple prosumers in one effective unit, smart communities make the integration of grid supportive prosumers even more attractive to DSOs.[8, 9] However, the grid-oriented operation of a prosumer´s household does impact the residents' demand behaviour tremendously if it is not coordinated properly with their desired schedule.

For this reason, this paper discusses a conceptual prosumer system that implements flexible device scheduling and an improved battery operation, aiming towards a grid signal-oriented system operation.[10] Here, the residents shall be able to dictate a desired operation time range for designated devices while the battery buffers unfavourable grid interactions. Although, the optimization is restricted by user demands, this approach will improve the resident's tolerance for the altered system operation and facilitate a real market implementation.[11] Focussing on a resident-friendly system design, the contents of the applied grid signal and its definition by the DSO or other suppliers are neglected.

Primarily, the referenced prosumer's household will be introduced with all its relevant electrical components. This system is to be optimized by a subsequently discussed home management unit, consisting - amongst others - of a data processing framework which interacts with the residents. As it will define the flexibility of the system, the grid signal-oriented optimization of both the flexible device scheduling and the battery operation was developed as a core functionality. Required data, implemented algorithms and final outputs will be described and discussed in detail. Finally, the assumptions made will be reflected with respect to "real world" aspects, enabling an ongoing development of the introduced concept.

Methodology

The reference prosumer system

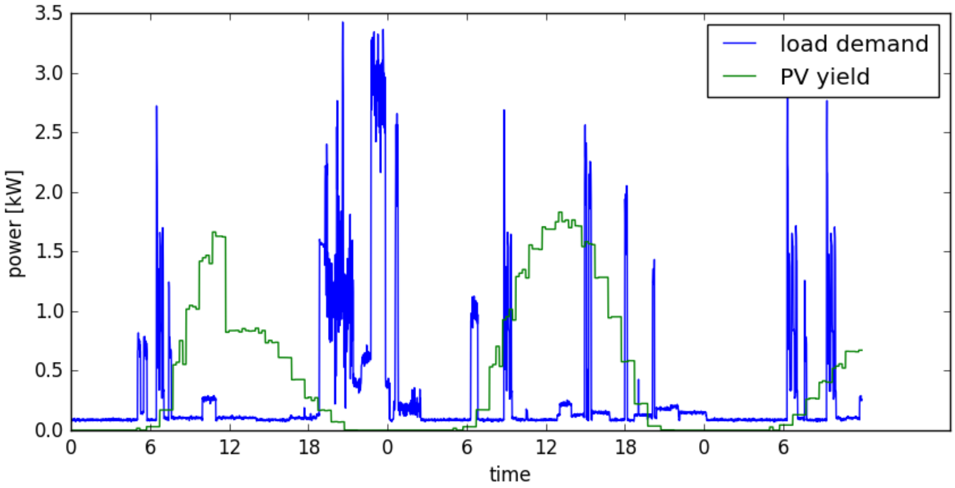
In this paper, the prosumer's household obtains its electrical energy both from an external grid and a local photovoltaic (PV) generator of defined rated power (*see figure A1*). To increase the direct consumption of the solar power, it is equipped with a battery storage that is controlled by a battery management system (BMS). The electrical load is subdivided in two groups. Non-flexible devices like room lighting, kitchen utilities or entertainment systems will be operated by the residents in a spontaneous and non-schedulable way and should thus be available any time. Consequently, this group is referenced as baseload. The second group includes flexible devices that to the max require the initiation of an unsupervised operation, like washing machines, dish washers or charging devices. These devices can be scheduled and enable an overall load profile optimization. Besides, the flexibility of a residential household can be extended even more by coupling related sectors like e-mobility or thermal energy systems, e.g., via heat pumps. However, this work primarily considers conventional electrical household devices to keep the initial approach at lower complexity. Hence, the reference system of a prosumer consists of a generating and a storage unit and has its individual composition of electricity consuming devices.

System model and simulation

Lacking a real system, all investigations described in this paper are based on a model simulation of the prosumer's household. The basic system operation was simulated on time series describing one week, including data for PV yield and baseload. Within this time, the operation of flexible devices was arbitrarily distributed over time in order to simulate the residents' device utilization.

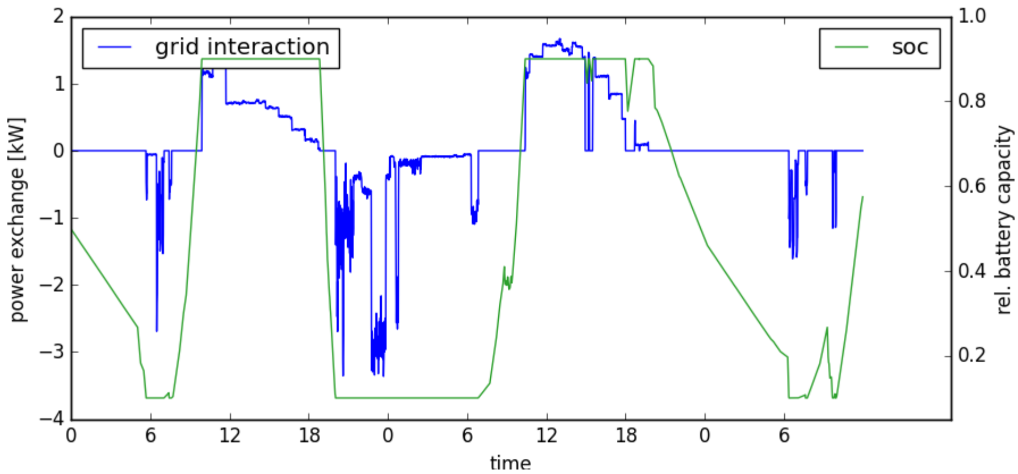
The so-called home management, representing the core component of this optimization approach, is a prediction-based data processing framework. This tool searches for an optimized system operation by simulating alternative model variations and therefore requires forecasted time series data describing the same quantities necessary for the basic simulation. Consequently, both the basic prosumer simulation and the optimization calculation are based on the same simulation model. The system is modelled via a simple iterative approach. Given both the initial battery state of charge (SOC) and system parameters like the battery´s capacity, system and conversion efficiency of the charging device, the system´s state of the next time step can be calculated using time series of the solar irradiation and the electricity demand. *Figure 1* compares the PV power, parametrized with a nominal PV power of 2 kilowatt peak (kWp), with the electrical load demand, clearly showing the temporal discrepancy.

Figure 1. Characteristics of PV yield and electrical load demand for a time span of 36h.



Since the battery charge is a function of all former generation-load-combinations, the following simulation shows a recursive behaviour which demands an iterative simulation approach. For the non-optimized reference system, it has been assumed, that surplus power from the PV generator is primarily charged into the battery and occurring power lacks, due to higher demand, are primarily compensated by the battery. If the battery storage is completely charged or discharged, the external grid is used to guarantee the generation-load-equilibrium. For the reference simulation, a nominal battery capacity of 2.5 kWh, battery load thresholds at SOC_{min}=10% and SOC_{max}=90% and an initial SOC of 50% have been chosen. The battery´s efficiency is at 95% and the inverters efficiency at 98%. Due to a constant baseload, the battery-stored energy is applied continuously to satisfy the demand. After 6 hours a first higher load occurs, leading to a total battery discharge. *Figure 2* shows the grid interaction necessary to compensate depleted battery capacities, where negative grid interaction shows power consumption from, and positive grid interaction power feed-in to, the external grid.

Figure 2. Result curves of the reference system simulation comparing grid interaction and battery's SOC



An important perception regarding *Figure 2* is the strict preference of utilizing the battery storage´s energy. Only if the battery capacities are exhausted, grid interaction takes place, which leads to an inflexible and non-grid-supportive power exchange.

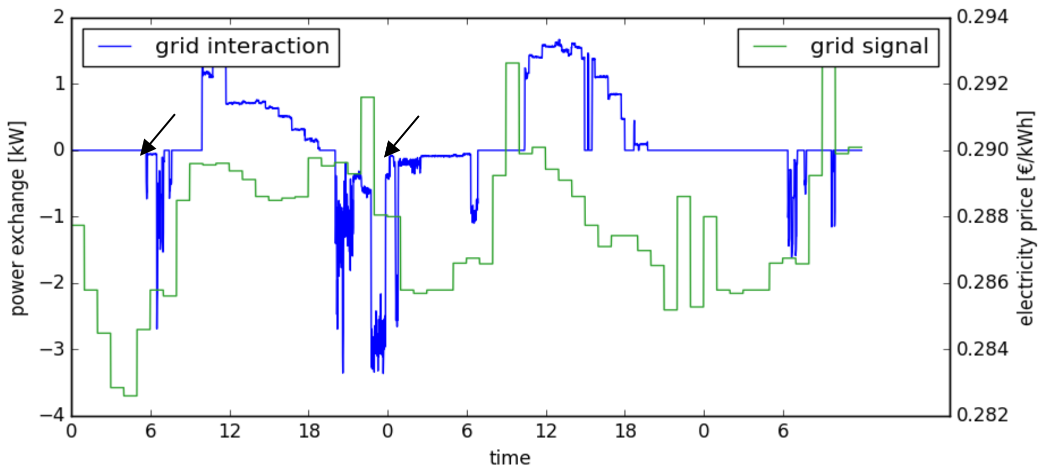
The home management

The core functionality of the home management is a simulation process that targets an optimized grid interaction. This improved operation could be supportive to grid regulation tasks or even to the reduction of residual grid load. Since optimization requires a kind of evaluation of the defined system, a grid signal is used to quantify the grid interaction with respect to the current grid state. Promising grid signals could be the available capacity of the local distribution grid or the residual load.

However, as this work focusses on the prosumer site of this demand-side-management approach, the nature of the finally applied grid signal is of lower importance here. So, for development purposes, an electricity price curve is used which assigns a price level to every 15-minute time step (*see figure 3*). But former studies already showed the negative impact broad prosumer applications have on the expansion demand of the local distribution grids if they are operated in a purely market-oriented way. Therefore, the electricity price could be seen as a CO_2 equivalent here, quantifying the emission of currently powering generation units.

The comparison of the chosen grid signal with the reference simulation obviously results in significant optimization potentials. *Figure 3* shows that there is no grid interaction at times with low electricity prices but there is interaction at times with higher prices. The unfavourable superposition of these both characteristics is to be optimized by the introduced home management.

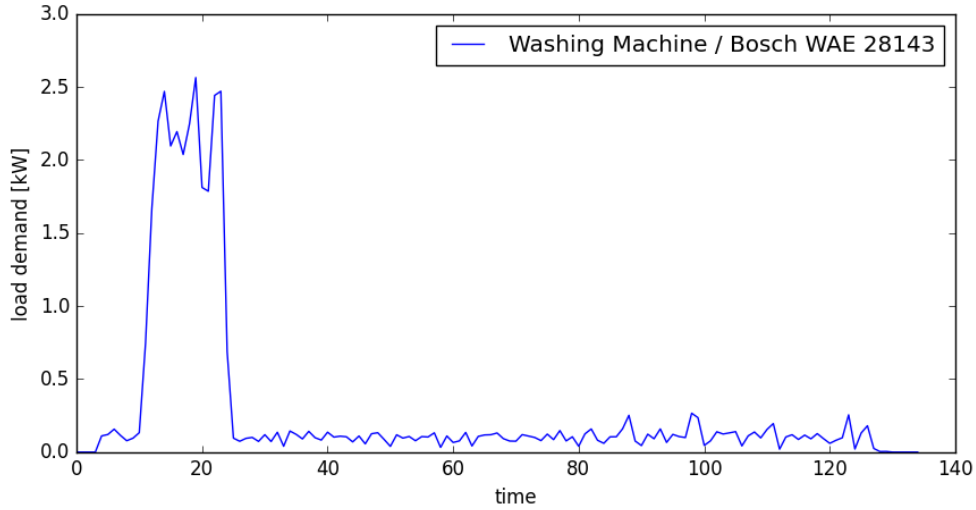
Figure 3. Electricity price curve compared to the grid interaction of the reference simulation. (arrow) unfavourable superposition of grid signal and grid interaction.



In real implementation, both the grid signal and the weather forecast would be gained as prediction time series of, for example, 36 hours from external service providers like for example the DSO and a local weather station, respectively. However, for development purposes, these time series were fed to the simulation as local files. While in this case the grid signal is a directly applicable information, the weather forecast needs to be converted to expected solar yields, using applicable system parameters like rated power and module efficiencies. Another required information for the optimization is the predicted baseload. Since this load is characterized by the residents' habits and by seasonal impacts, it represents an individual curve for each household. For this reason, it needs to be predicted by an appropriate, internal forecast algorithm, learning from historic data, consisting of data measured at crucial system nodes (*see figure A1*). Consisting of an arbitrary number of devices, the baseload can´t be measured at some selected points of operation but is calculated as the difference of the overall load demand and the currently operating flexible devices. For simplicity purposes in this work, these predictive time series, as well as all other time series describing load characteristics, were extracted from the LoadProfileGenerator by Noah Pflugradt [12]. The devices considered in this approach can be found in the appendix listed in *table T1*.

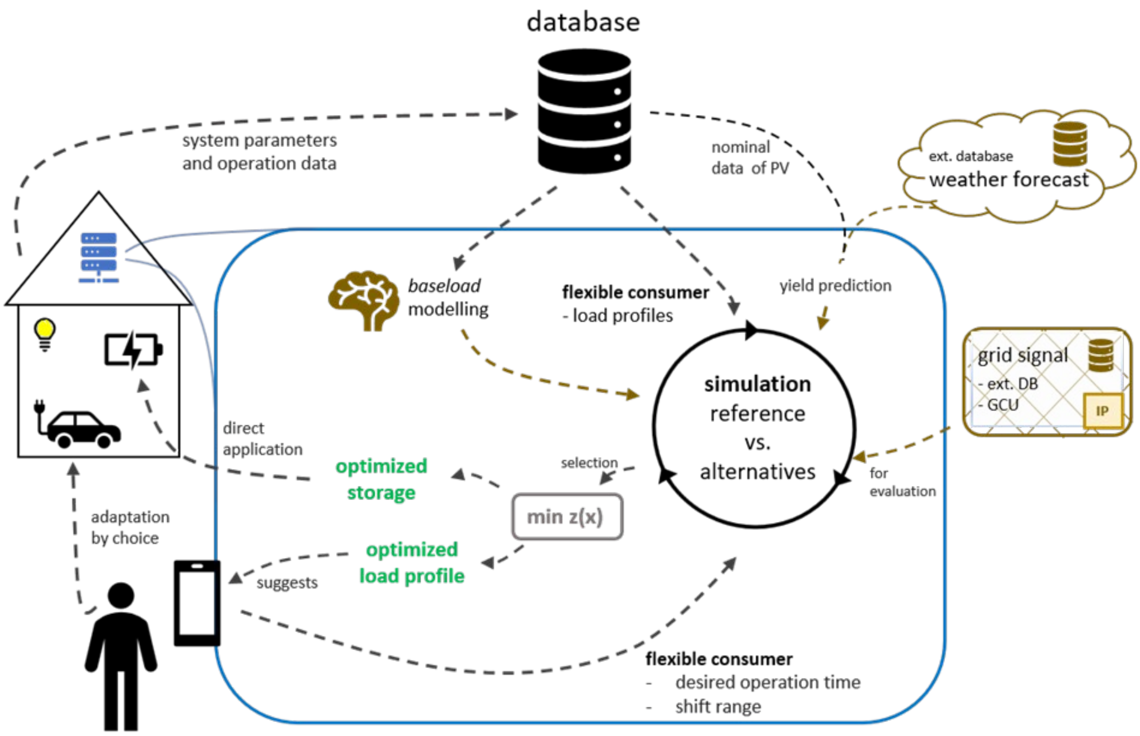
The residents' requirements shall be fed to the home management by the residents manually via a proper user interface like an app, defining an acceptable time range for the flexible devices to be operated. Within this range, the home management is enabled to optimize the device operation schedule which is then finally reported to the resident. To be able to evaluate the impact of a shifted load schedule, the home management needs to know the exact load profile of each designated flexible device (*see figure 4*). This information could be either gained by an initial measurement after the device´s installation or supplied by cooperating manufacturers.

Figure 4. High resolution load profile of a washing machine. [12]



Knowing both the future solar generation, occurring baseload and the forecasted grid signal, the home management is equipped with any predictive time series necessary to forecast the systems future states. By changing the start times of the flexible load profiles and by modifying the battery operation mode, it is now even able to simulate alternative system operation and to find an optimized grid interaction (*see figure 5*).

Figure 5. Data processing framework of the home management. (brown) prediction data. (green) optimization results. (blue) home management optimization process.



Based on the underlying simulation model and all required data, the core functionality of the home management, the optimizing data processing, will be introduced next.

The cost function

As a first step, it is necessary to define a cost function that quantifies the quality of the system operation with respect to the grid signal. Here, a so-called grid support coefficient (C_{GS}) introduced by Klein et al. [13] is used (*see formula 1)*. It allows to declare grid interaction either as grid-supportive or non-grid-supportive, regardless of the underlying type of grid signal. The C_{GS} is defined by the quotient of the summed grid signal during electricity demand and the globally averaged grid signal within the whole considered interval:

$$C_{GS}(G) := \frac{\sum_{i=1}^{n} W_{el}^{i} \, G^{i}}{W_{el} \; \bar{G}} \; [-] \qquad (1)$$

Here, W_{el}^{i} is the electrical power taken from grid and G^i the grid signal at the time point with index i. The overall energy taken from the grid is defined by $W_{el} := \sum_{i=1}^{n} W_{el}^{i}$ [kWh], and the averaged grid signal by $\bar{G} := \frac{1}{n} \sum_{i=1}^{n} G^{i}$. By comparing the used grid signal to the mean value of grid signals, where the latter includes moments without grid interaction, the power exchange can be described as non-supportive, that is a C_{GS} (G) > 1, or supportive, that is C_{GS} (G) < 1. Hence, the quotient is a qualitative metric which will be base to the following optimization.

Optimization approach

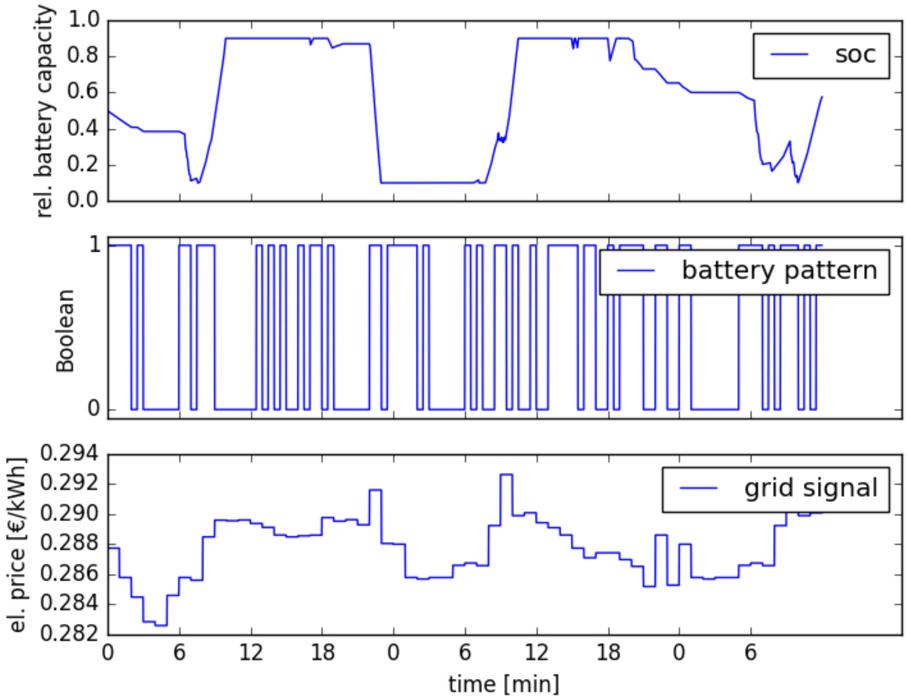
The optimization targets an altered system operation strategy that shows, in comparison to the current, non-optimized reference strategy, a grid supportive C_{GS} below 1. Given the forecasted time series of baseload, weather and grid signal, a modification of the flexible device schedule as well as the battery operation may create an improvement in operation.

Due to the recursive nature of the system caused by the storage unit, it is not possible to calculate the system operation at some point of time without knowing the preceding system states. Consequently, the overall grid interaction can´t be described in one minimizable function looking for the optimum operation type. Instead, each alternative system operation needs to be simulated over the complete time range to evaluate its resulting grid interaction. For this reason, multiple alternative schedules and battery operations need to be simulated during optimization, whereas a minimum number is desired in order to reduce the computational effort. Therefore, a useful technique is the so-called genetic algorithm. This iterative optimization approach performs a stochastic search for a global minimum in a provided solution pool. Calculating several numbers of generations, it recombines randomly properties of the fittest solutions and additionally changes the solution pool regularly by applying mutations [14]. A restriction to this approach is the requirement of a discrete solution space. To fulfil this requirement, the possible shift range of the flexible devices and the battery usage need to be formulated as a problem with a finite number of solutions.

At first, the schedule of the flexible devices is determined by the residents' input. To do so, they have to designate the devices to be run in a desired time interval. This interval is defined by an initial start time combined with an accepted shifting range back and forth in time. By discretising this time range, a finite number of alternative start times can be provided to the system. The higher this number, the higher the computational effort, but also the higher the theoretically achievable optimization potential. The battery operation has been designed modifiable by a so-called battery pattern. This pattern consists of a Boolean mask that divides the considered time range in a finite number of time slots. Each of these time slots is characterized by a corresponding flag in the battery pattern that either allows the utilization of battery power to supply occurring loads or prohibits the same. An increasing number of time slots allows a higher adaptivity of the operation on the one hand, but at the same time requires way higher computational effort and conflicts with the physical abilities of real batteries. Here, the time slots of the battery pattern describe 15-minute intervals. *Figure 6* shows how the battery power is applied to loads following the described pattern. In times with low grid signal the grid interaction is preferred while in times of high grid signal the battery utilization is prioritized.

With these two discrete problem formulations, different operation alternatives for the time range within the prediction horizon can be defined precisely by both the permission of the battery usage and the planned start of device operation at each time point. A random variety of these individual solutions is fed to the genetic algorithm building the genetic pool that undergoes evolution in order to find the fittest individual. The fitness of each individual is thereby quantified by the introduced grid support coefficient.

Figure 6. Controlled battery usage via Boolean battery pattern.



Now, to optimize the grid interaction, the home management varies the start times of the demanded flexible devices in the first place, followed by the adaptation of the battery operation to the predicted grid interaction. This system improvement needs to be done periodically to update and adapt the optimization regularly. As an appropriate updating period, 6h were selected (*see figure A2*).

Results

By optimizing both the flexible device schedule and the battery operation, an improved grid interaction could be achieved. In this analysis, 60 h of system operation were simulated. Both the flexible device shifting range and the battery operation time range were subdivided into 15-minute time slots to generate a discretised optimization problem. The prediction horizon for the simulations was set to 12 h.

Figure 7. Electrical load demand of reference and optimized simulation. (arrows) shifted flexible device schedule.

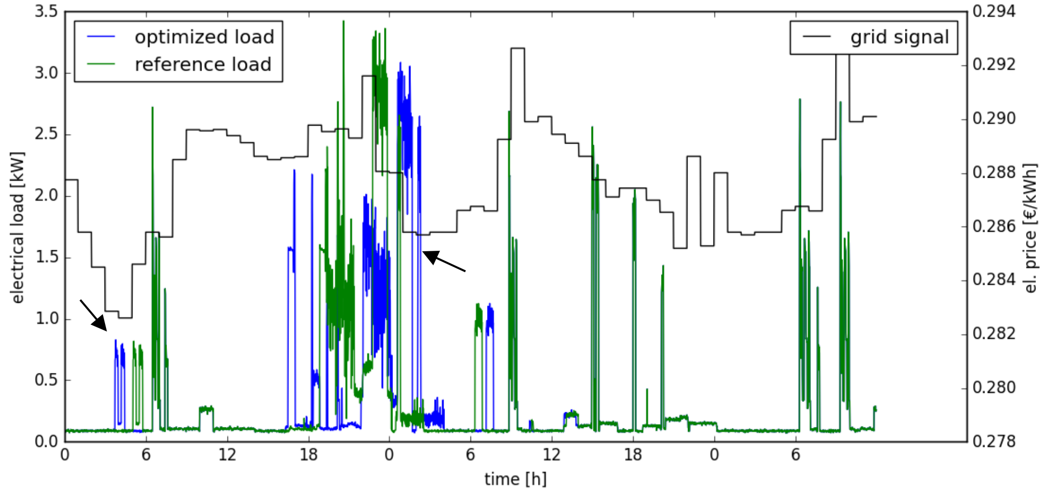
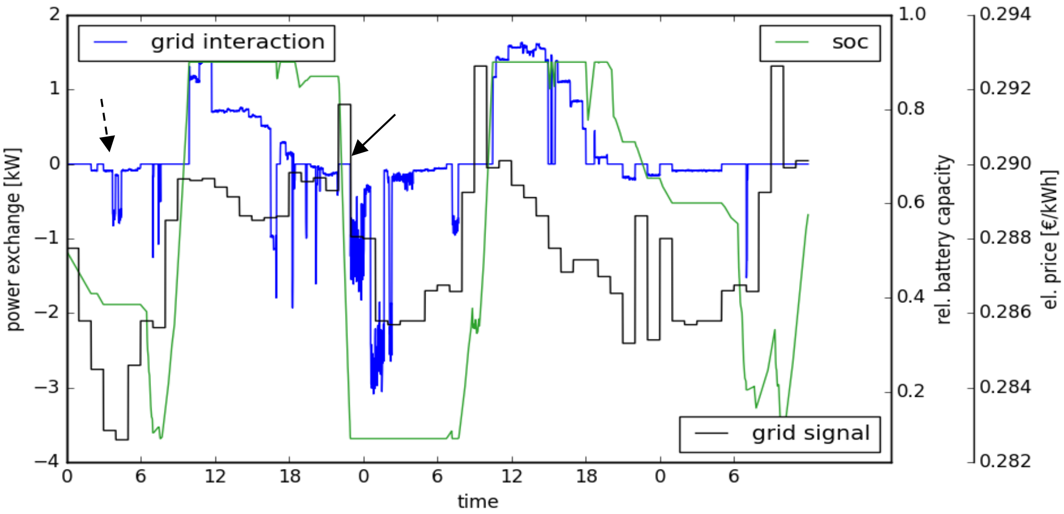


Figure 7 illustrates the resulting difference of the non-optimized reference and the optimized system operation by means of the finally applied electrical load. It shows that the home management shifted several flexible devices to times of lower grid signals.

Additionally, the home management adjusted the operation times of the battery storage in a way that its capacity is now primarily used in moments of higher grid signals. *Figure 8* shows, that the optimized system interacts with the external grid mainly in times with lower grid signals. In contrary to the reference simulation, the two available energy sources, i.e., the external grid and the battery storage, are no longer used in a battery dominant but in an alternating, flexible way.

Figure 8. Result curves of optimized simulation. (arrow) Avoided grid interaction. (dotted arrow) Preferred grid interaction**.**



The altered grid interaction is achieved both by scheduling flexible loads to better suited operation times and by coordinating battery and grid application. A remarkable difference between the first and the latter way is that the battery optimization only shifts the moment of grid interaction whereas the scheduling of flexible devices is even able to alter the overall amount of required grid energy. Furthermore, by optimizing the flexible devices' schedule, the time with fully charged or discharged battery is reduced which corresponds to an increased direct consumption.

Quantifying the grid interaction, the C_{GS} of the reference simulation was at 1.002, which corresponds to a slightly non-grid-supportive interaction. By means of the optimization, a grid-supportive interaction was achieved with a C_{GS} of 0,996. To express the results in a grid signal specific context, a revenue of 8.56 ct/kWh [15] for feeding energy to the grid is assumed. By integrating the product of this revenue and the energy fed to the grid a resulting profit can be calculated. On the other hand, by integrating the negative values of the grid interaction with the corresponding grid signal values, the costs for the required grid interaction are gained. By taking the difference of profits and costs, overall resulting operation costs of 1.24 € could be calculated for the reference system, whereas the optimized solution end up with 1.14€.

Discussion

The concept of a home management introduced in this paper could be tested successfully in its basic mechanisms. Primarily, the optimizing core functionalities has been developed by means of synthetic data, which uncovered all the measuring, forecast and input data required to proceed with tests under real conditions. Moreover, the system concept illustrated in *figure 5* could be translated into a modular program structure, enabling to continue working out the components in future work. For example, the internal baseload prediction which requires specific development to achieve a prediction time series of sufficient quality, has been integrated as a simplified program module for now. A promising approach therefore is the application of pretrained recursive or convolutional deep learning models which, due to the pretraining, would require only a reduced effort for adapting to the system and could be trained continuously on the system´s historic data. Also, the used simulation model necessary for the prediction-based optimization needs to be easily adaptable by enabling component modifications or the modification of certain component characteristics.

The discrete problem formulation of the flexible load schedule and the battery operation already allows an efficient and easily controllable optimization processing by means of the genetic algorithm. But it also shows a trade-off between the computational effort and the accuracy of the resulting optimization, that is to be considered. The higher the number of time slots used to discretise a time interval, the higher the number of alternative solutions for the system optimization and the higher the computational effort to find a global optimum. However, by using time slots of 15 minutes, a precise adaptation to the grid signal could already be verified. Moreover, this resolution is also valid for standardized profiles and prognosis data applicated to the German regulatory process Redispatch 2.0.[16]

An important aspect of this concept is the consideration of the residents' requirements in order to raise the attractivity and to minimize any loss of comfort. Therefore, a simple data interface for the resident is target, enabling both the input of desired operation times and the output of suggested operation times. Thus, the user can easily benefit from but is not bond to the optimization procedure. In that context it is advantageous that, due to the automated nature of the battery operation, the system is getting more grid-supportive even without any user interaction.

If this system concept is applied in terms of grid stability tasks, it needs to be taken into consideration that the grid-signal-providing system operator requires a predictable load characteristic in order to reduce expensive power compensation measures. Consequently, a prosumer optimization with respect to the residents' comforts bears a risk of not being able to forecast the upcoming load demand. Therefore, it would be possible to only apply flexibilities provided by storage units since they don't depend on the resident's interaction. But this approach would neglect the flexibility potentials of respective devices. Another interesting application would be the integration of this home management concept into in micro grid solutions like smart communities. Consisting of multiple battery storages and a higher number of flexible devices, smart communities would have an even more positive impact on grid stability and, at the same, time would be less sensitive to uncertainties in the realizations of optimized schedules. Hence, it bears less risk for the DSO to rely on such ancillary services making them realistically more applicable. In this case, the available battery storages could be seen as one virtual storage and optimized by the home management system in a similar way.

Finally, the nature of the grid signal is not relevant to the functionality of the optimizing algorithm, but rather is a crucial factor defining the effective impact of the altered system operation. Applied with a grid-capacity-representing metric of the local distribution grid, a managed prosumer micro grid can support the observance of voltage thresholds, which is, especially in the context of an increasing number of decentral PV generators, an interesting opportunity for DSOs. However, in order to generate an appropriate grid signal, todays DSO are forced to expand the monitoring of crucial low voltage grid components. Another promising grid signals are the residual load representing the share of conventionally generated power in the electrical grid, or a CO_2 equivalent, quantifying the emissions required to supply the power to the consumers. Both grid signals transmit analogue information and target the reduction of emissions for electricity generation. Especially in the context of the Emissions Trading System (ETS) introduced by the EU, these latter grid signals bear the potential of promoting an emission free generation, since a reduced demand for conventional energy makes its generation less economical.

Summing up, the integration of prosumer applications into the electrical power supply system as active participants demands a robust and bilateral data communication infrastructure and data processing. However, regarding the progress in Redispatch 2.0 and the smart meter roll-out, required experience in prognosis-based grid regulations are gained and applicable hardware is getting installed already. To further develop the system concept of this home management, the simulation model needs to be designed more realistic, e.g., with respect to the battery operation capabilities, and the availability of prognosis data needs to be investigated and combined with long-term simulations. Therefore, a basic deep learning model needs to be pretrained for this problem and adapted to a specific household by means of measured historic baseload data. Additionally, possible providers for supplying grid signals and weather prognosis need to be identified. While forecast data describing the grid capacity can be transmitted by the DSO, data describing CO_2 equivalents could be supplied by interregional providers, although, due to regulatory reasons, the DSO still needs to be involved in that process. To motivate the residents to enhance their efforts in rescheduling their habits it is also necessary to concept a market model that defines revenues and commitments for both the prosumer households and the system operator. So, in the context of a steadily decentralized grid, a growing number of e-mobility and increasingly digitalized grid operation, the integration of optimized smart communities is to be seen as an essential step towards an emission free energy supply.

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Appendix

Figure A1. Scheme of a prosumer's household with DC-site battery coupling. (1) external grid. (2) electricity meter. (3) non-flexible devices. (4) flexible devices. (5) inverter. (6) inverter with integrated battery controller. (7) battery storage. (8) solar generator. (9) heat pump. (a+b) grid interaction measurement. (c) Battery state of charge (SOC) measurement. (d) PV-power measurement. (e) Flexible device load measurement.

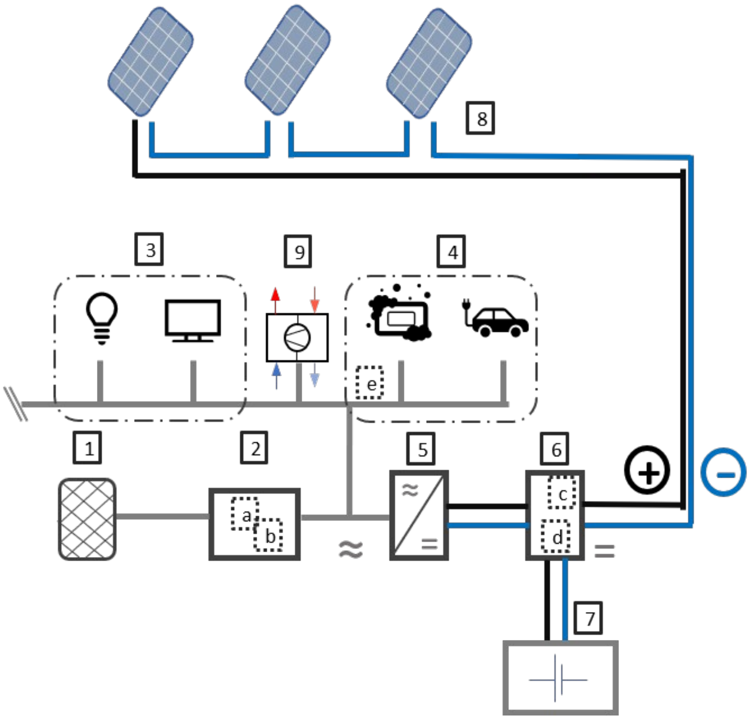

Figure A2. Cyclic calculation of system optimization

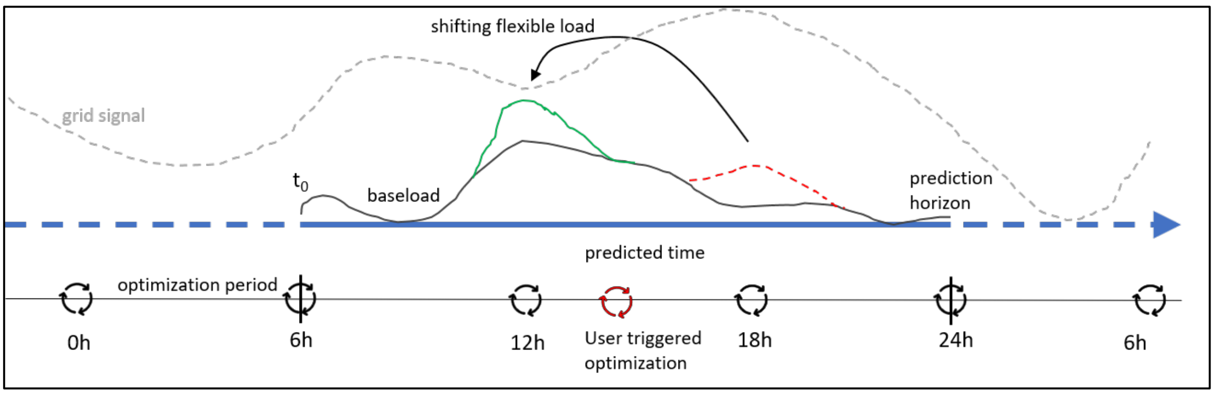

Table T1. List of electrical devices considered as installed in the simulated household.

Electrical devices considered for simulation	
Kitchen - Kitchen Light (20W) [kWh]	Living room - SAT Receiver / Kathrein UFS913 [kWh]
Kitchen - Washing Machine / Bosch WAE 28143 [kWh]	Living room - Steam Iron / Phillips GC 4410 [kWh]
Kitchen - AFK BM-2N [kWh]	Living room - TV Medion MD20123_DE_A [kWh]
Kitchen - Egg Cooker / Russell Hobbs 14048-56 Stylo [kWh]	Living room - Living Room Light (Energy Saving Lamp, 20W) [kWh]
Kitchen - Juicer / Moulinex Vitafruit [kWh]	Living room - Nespresso Coffee Machine, Single Cup [kWh]
Kitchen - Kitchen radio / AEG KRC 4323 CD [kWh]	Living room - Energy Saving Lamp / EL-REF 11 E27 [kWh]
Kitchen - Nespresso Coffee Machine, Single Cup [kWh]	Living room - CD/DVD Player / Philips DVDR 725 H [kWh]
Kitchen - Food Slicer / DOMO Schneidemaschine DO521S [kWh]	Living room - Christopeit Treadmill TM 2 Pro [kWh]
Kitchen - Toaster Salco MT 400 [kWh]	Living room - Laptop Sony Vaio SVE151G11M [kWh]
Kitchen - Miele DG 1450 [kWh]	Living room - SAT Receiver / Kathrein UFS913 [kWh].3
Kitchen - Handmixer / Phillips Robust HR 1581 [kWh]	Living room - TV Medion MD20123_DE_A [kWh].3
Kitchen - Kitchen Stove / Bauknecht Heko 750 PT Kitchen stove	Living room - Home Server 50 W [kWh].2
Kitchen - Kitchen Stove / Bauknecht Heko 750 PT Kitchen stove	Living room - Electronic Hometrainer / Kettler Satura E [kWh].3
Kitchen - Kitchen Stove / Bauknecht Heko 750 PT Kitchen-stove	Living room - Router O2 Box 6431 [kWh].2
Kitchen - Microwave / Panasonic NN 5259 [kWh]	Bath - Hair Dryer Braun Silencio 1250 [kWh]
Kitchen - Extractor Hood / Miele DA 429-4 [kWh]	Bedroom - Bedroom Light (20W) [kWh]
Kitchen - Miele DA 61 [kWh]	Bath - Electric Toothbrush Dondodent Professional Clean [kWh].2
Kitchen - Bauknecht GTE 260 [kWh]	Bath - Bathroom Light (20W) [kWh]
Kitchen - Dishwasher NEFF SD6P1F (2011) [kWh]	Bath - Bathroom Mirror Light 10 W (LED) [kWh]
Kitchen - Dryer / Miele T 8626 WP [kWh]	Bath - Electric Razor Braun Cruzer 5 [kWh].2
Kitchen - Vacuum Cleaner Robot / iRobot Roomba 555 [kWh]	Kitchen - Clatronic MS 3249 Milk Foamer [kWh]
Kitchen - Siemens KI 20 LA 65 (A+) [kWh].2	Kitchen - Electric Kettle / Petra WK288 1.5L [kWh]
Kitchen - Microwave / Panasonic NN 5259 [kWh].3	Humidifier DeLonghi UH 800E [kWh]
Kitchen - Blender Vitamix Moulinex [kWh]	

(green box) flexible device.

Source: [12]

A baseline assessment of residential utility rates and compensation mechanisms that influence the value proposition of grid-interactive efficient buildings

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Abstract

Grid-interactive efficient buildings (GEBs) integrate intelligent technologies, energy efficiency, and distributed energy resources that generate value to a range of stakeholders including the GEB owner, the electric grid, the environment, and society. The right combination of utility policies must be implemented to incentivize the operation and adoption of GEB-enabling technologies to fully realize this value. Utility policies vary widely across the United States due to differences in utility ownership types, regulations, and the local mix of energy generation sources. Consequently, the value proposition of GEBs also varies across the country. Limited research to date has tried to understand how this value is affected by utility policies. To address the research gap, this work surveys the current landscape of residential utility rates and distributed generation compensation mechanisms in the United States, highlighting likely interactions between utility policies and GEBs and identifying potential regions for early adoption.

Introduction

The proliferation of smart technologies and demand side management practices that offer increased energy demand flexibility from buildings has paved the way for to the grid-interactive efficient building (GEB). GEBs are energy-efficient buildings that also integrate intelligent technologies and distributed energy resources (DERs) to optimize energy assets, fulfill occupant needs and preferences, provide services to the grid, and generate cost savings [1]. While GEBs incorporate technologies into the architectural, electrical, mechanical, plumbing, and controls aspects of the building [2], they can extend well beyond that to incorporate other DERs such as solar photovoltaics (PV), battery storage, and electric vehicle charging [1]. The likelihood of GEBs incorporating additional DERs is probable given the already significant deployment of small-scale solar PV systems [3] and outlook for battery storage [4]. With a diverse set of technologies that have a range of capabilities, the potential for GEBs to generate value spans a large group of stakeholders including the electric grid, building occupants and owners, utilities, society, and the environment. This value can manifest in many ways including, but not limited to, a reduction in energy bills, a more reliable electric grid with higher contributions of renewable energy sources, and avoided greenhouse gas emissions. Some sources of value may be difficult to realize, such as increased comfort within the home, given the tension created by different characteristics of a GEB. For example, while increased energy efficiency is often associated with improved comfort levels, optimizing energy consumption may result in changes in energy behaviors for occupants. With such changes in behavior, avoiding sacrifices in comfort becomes more material than increasing levels of comfort. Overall, the potential value proposition of GEBs to stakeholders is vast with two stakeholders being key to GEB adoption, long-term success, and sustainability: building owners and the electric grid. Building owners who install and maintain GEB-enabling technologies must realize tangible value, and the electric grid must realize benefit from GEBs for utilities to support and integrate their contributions. The way in which value accrues to both stakeholders is largely dictated by the capability of the technologies within a GEB, how those technologies are operated, and the utility policies that govern them.

Through a combination of flexibility and energy efficiency, GEBs hold real promise to generate value through a reduction in generation and peak demand [5]. However, limited work to date has focused on the impact that existing utility policies have on the value proposition of GEBs and buildings with increased flexibility more generally. Two seminal pieces of work [6, 7] inform this body of knowledge. The first from O'Shaugnessy et al. [6] optimizes the economic value to the customer in homes with solar PV, battery storage, smart domestic hot water heaters, and smart AC units. This work assumes a series of utility policies that are unfavorable to standalone PV systems (i.e., grid export rates that are less than what the customer is billed per kWh, time of use (TOU) rates that occur during times when PV is not at its peak, and demand charges) to determine if the increased flexibility introduced by battery storage and intelligent loads decreases the negative impact that utility policies can have on standalone PV systems. In comparison, Shah et al. [7] evaluate customer and grid benefits that GEBs generate under a single TOU rate local to their study location and a flat rate with net metering (i.e., the customer is compensated for the net energy they export to the grid); proxy real time prices that vary by hour are also considered. While both studies begin to quantify the value of GEBs, they are restricted in geographic scope and the utility policies considered.

The impact utility policies have on individual DERs, particularly solar PV and battery storage, has been addressed more extensively. The literature explores both a broad range of utility policies such as flat rates, TOU rates, demand charges, and compensation mechanisms of different relative magnitude [8-10] as well as the metrics that can be used to measure value generated by technologies under those policies in diverse settings. From levelized cost of energy and internal rate of return [10] to net present value and levelized value of energy [11], customer value can be measured through a number of metrics. Given that increased flexibility from technologies shows promise for increasing the value of GEBs relative to standalone solar PV under specific utility policies [6], understanding the structure of those policies more thoroughly across the United States is necessary to support deployment of GEBs at scale and allow for the value proposition to be accurately estimated. Through such an understanding, favorable markets for early adoption can be identified and the technical research for optimizing the technologies within GEBs can be better informed to reflect existing and future policies.

To enable such an assessment, the current landscape of utility policies in the United States must first be understood. Existing work has considered specific types of rates [12] or compensation mechanisms [13] in the United States but has not directly addressed their interaction with GEBs or reflected the entire landscape of utility policies that can affect their value proposition. The number of periods within rate structures, the schedule for TOU rates, and the number of tiers within a given period of a rate structure are among the factors that could affect the value generated by GEBs' increased flexibility and energy efficiency. As the electric grid transitions to a future where customers evolve into prosumers that both supply electricity to the grid as well as consume it, the structure of utility policies will elicit demand-side behaviors that benefit the grid. Tiered rates, for example, can promote energy efficiency by incentivizing customers to keep their overall consumption levels low and TOU rates can promote energy shedding or shifting away from peak periods of the day. The specifics of these rates vary depending on the customer class, utility ownership model, and location. As technologies evolve to enable GEB capabilities, it is necessary to understand the existing trends in utility policies when considering the cost effectiveness and ability to realize the value that GEBs can generate.

This work provides a baseline assessment of both electricity rate structures and distributed generation compensation mechanisms within the residential sector by utility type in the United States, and it places GEBs within this landscape.

Background

Current electricity rate structures in the United States take on a range of forms including flat rates, tiered rates, and TOU rates. Flat rates remain constant over the course of a long timeframe (e.g., season or year) and culminate in a single per-kWh charge that is multiplied by the amount of energy consumed. Tiered rates increase in complexity when compared to flat rates. Instead of a single rate per kWh consumed, customers are charged a designated price per kWh up until a certain threshold of energy has been consumed over a preset duration of time (often a billing cycle). Once that threshold has been surpassed, customers are charged a new price per kWh. The number of tiers within a rate, magnitude of consumption thresholds for a tier, and duration of time before the rates reset can vary from utility to utility. While increasing a building's energy efficiency under flat rates can generate savings on customer bills and lessen the strain on the electric grid by reducing the overall demand, tiered rates can further promote energy efficiency since customers are often charged less per kWh in the first tier of their rate; if they can stay below a certain threshold, they do not pay the premium associated with more consumption. Neither of these rates, however, incentivize change in the time of day that energy is consumed.

TOU rates vary based on the time of day, and sometimes time of year, electricity is consumed. Under a TOU rate, an individual day is typically broken into periods that are at least one hour in duration or longer, and a price per kWh is assigned to each of those time periods. TOU rates promote energy shedding and shifting given that the price customers are charged during certain times of the day is higher than others. If the price differential between periods is significant, customers can realize cost savings through such behaviors, and the demand on the electric grid can decrease during peak periods.

Electricity rates can be a combination of these structures as well, incorporating tiers into individual TOU periods for example. Demand charges may be applied. Demand charges bill customers for the peak amount of power that they require over some predetermined time. Other types of rate structures for charging customers, such as critical peak pricing and critical peak rebates (i.e., rates that incentivize a decrease in consumption during an identified period of high demand) and real time pricing (i.e., prices at sub-hourly increments reflecting dynamic grid needs), are not considered. Fixed charges are also excluded. These rate structures and bill components are beyond the intended scope of this study.

Given the potential for GEBs to export electricity to the grid, it is necessary to understand the current landscape of compensation mechanisms available to customers. Generally, these options include net metering, net billing, and buy all-sell all methods. While all these options credit customers for electricity exports, the way in which they do so and the equipment necessary for each vary from one mechanism to the other. The nuances in these mechanisms can influence the value generated to the customer and the likelihood of a customer installing technologies that would allow them to participate in such a program.

Both electricity rates and compensation mechanisms vary by location and utility ownership model. Location holds a strong influence over utility policies due to local fuel prices, the availability of power plants, and pricing regulations [14]. Similarly, the different types of utility ownership models motivate utility actions. While private utilities such as investor-owned utilities are owned by stakeholders and investors and set rates to recover costs and earn a reasonable profit, public utilities such as cooperatives and municipal utilities are owned by members or government bodies, respectively, and set their rates to recover costs and support future investments. Private utilities have their rates approved by public utility commissions, and public utilities have their rates approved by a governing board or members [15]. All these factors have the potential to influence the landscape of utility policies across the United States. The data and methods used within this study are described in the section that follows.

Data and Methods

To understand the utility policy landscape in the United States, the National Renewable Energy Laboratory's Utility Rate Database (URDB) [16] was surveyed. The URDB is an open-source database containing utility rates from across the United States. As of April 8, 2021, the URDB contained 49,791 rates, of which 11,268 or 23% were residential rates. While these rates date back to 1969, a subset of 3,791 rates was used to determine the current landscape of utility policies; only rates that started on or after January 1, 2016 and did not have an expired end date were considered in this study. Given that rates are only periodically updated in the URDB, this subset spans five full years of data, highlighting recent policies while still providing coverage across the United States. The number of periods, the price charged within each period, the number of tiers in each period, whether a demand charge is levied, and the schedule of periods are known for each rate. Since the schedule of rates is known over the course of a year, rates were categorized as flat, seasonal, daily TOU, and seasonal TOU rates as defined in Table 1.

Table 26. Types of rates identified within the URDB.

Rate Type	Definition
Flat	Flat rates have one period in their schedule for every hour of the day, all year long.
Seasonal	Seasonal rates have more than one period, varying in price by month of the year but not time of day.
Daily TOU	Daily TOU rates have more than one period, varying in price by time of day. The rates during those periods and the schedule of those periods remain constant over the course of the year.
Seasonal TOU	Seasonal TOU rates have more than one period and vary in price by both time of day and time of year.

For each rate in the URDB, there is a possibility for the rate to have an associated compensation mechanism for distributed generation. Rates can be marked with net metering, net billing, or buy all-sell all. Definitions for these mechanisms are described in Table 2.

Table 27. Types of distributed generation compensation mechanisms in the URDB. Definitions are adapted from [17].

Compensation Mechanisms	Definition
Net Metering	Net metering policies often, but not always, compensate customers at the retail rate. A bidirectional meter or two unidirectional meters are required, and self-consumption is allowed.
Net Billing	Net billing policies typically compensate customers at prices less than the retail rate. Two meters are required, and self-consumption is allowed.
Buy All, Sell All	Buy all, sell all policies prohibit self-consumption and compensate customers at some predetermined rate. Two unidirectional meters or a single smart meter is necessary.

Each rate in the URDB is linked to an Energy Information Administration (EIA) recognized utility. Every EIA-recognized utility has an associated ID number that was mapped to utility service territories in the *Electric retail service territories* database [18]. This matching enabled a breakdown of utility rate structures and compensation mechanisms by utility ownership type and geographic region. Census regions—Midwest, Northeast, South, and West—are used. If a utility's territory enters more than one region, it is counted in both.

To understand the landscape of utility rates within the context of the value generated by GEBs, the rates for each utility ownership type in each region were analyzed to determine the likelihood that flat rates, seasonal rates, daily TOU rates, or seasonal TOU rates are offered. The TOU rates were further analyzed to consider the ratio between the first tier in the first period of the rate and the first tier in the second period of the rate. The difference in price during those periods will influence a customer's likelihood to shift away from peak periods, generating both value for the grid and potential savings for the customer. The number of periods within those rates are extracted, and the schedule of the periods are compared. The tiers within all rates, regardless of whether they are flat, seasonal, or TOU rates, were also analyzed given that they promote energy efficiency.

While the subset of rates did not provide complete coverage across the United States, rates were available for every state in the subset of URDB data used for this study as visualized in Figure 1. A total of 387 utilities were represented, with 130 in the Midwest (44% investor owned, 39% municipal, 17% cooperative), 42 in the Northeast (83% investor owned, 10% municipal, 7% cooperative), 134 in the South (48% investor owned, 23% municipal, 29% cooperative), and 81 in the West (41% investor owned, 27% municipal, 32% cooperative). The utilities in this sample provide electricity to more than 85 million residential customers out of an estimated 136 million [19] that are served by roughly 3,000 utilities across the country [20]. Out of the total sample of rates, TOU rates were present for 160 utilities. This includes 45 utilities in the Midwest (87% investor owned, 4% municipal, 9% cooperative), 25 in the Northeast (96% investor owned, 4% cooperative), 55 in the South (75% investor owned, 5% municipal, 20% cooperative), and 35 in the West (66% investor owned, 11% municipal, 23% cooperative).

Additionally, over 60% of the rates contained information on compensation mechanisms, categorizing them as either net metering, net billing, or buy all-sell all. These compensation mechanisms are employed by 196 utilities in the subset of data including 53 utilities in the Midwest (85% investor owned, 7.5% municipal, 7.5% cooperative), 30 in the Northeast (97% investor owned, 3% cooperative), 82 in the South (56% investor owned, 13% municipal, 30% cooperative), and 31 in the West (68% investor owned, 19% municipal, 13% cooperative). The utility territories that listed compensation mechanisms for their rates are shown in Figure 2. The sell rate was available for less than 1% of these rates, so it was excluded from this study. The categorization of compensation mechanisms provides high-level insights about the way electricity exported to the grid is currently valued. This is critical in GEB adoption and operation since the willingness of utilities to compensate customers for exported electricity influences technology adoption decisions and the optimization algorithm with GEBs. The results from this assessment are presented in the next section.

Figure 46. Utility territories that have rates in the subset of URDB data used within this study. Territories are marked according to the legend. Darker shades represent territories with utility overlaps, and white spaces indicate territories with no available data.

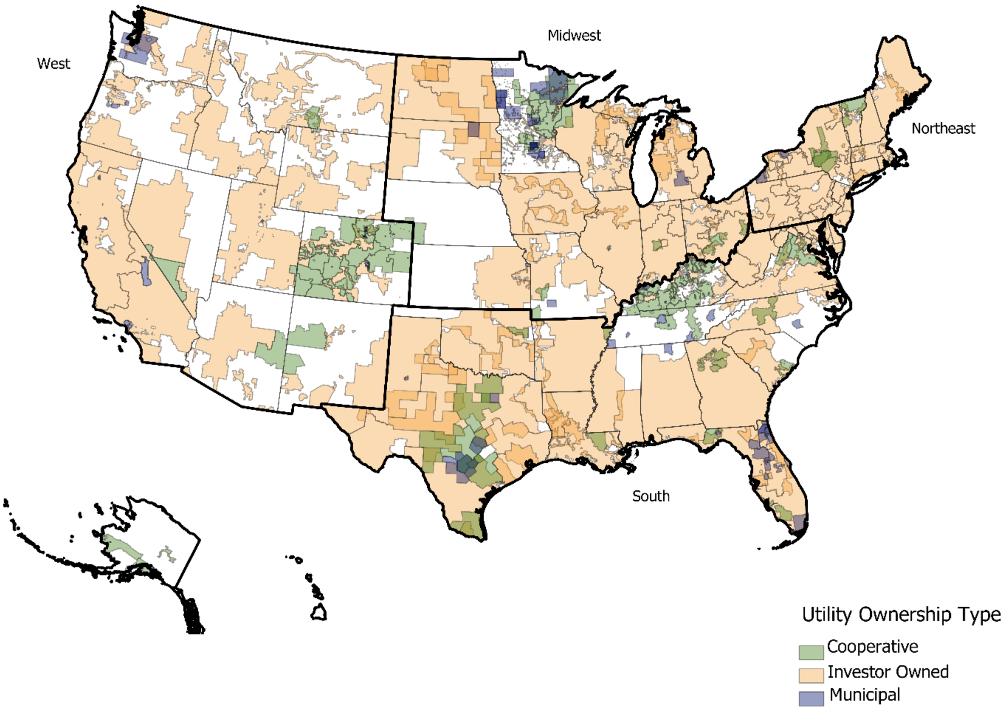
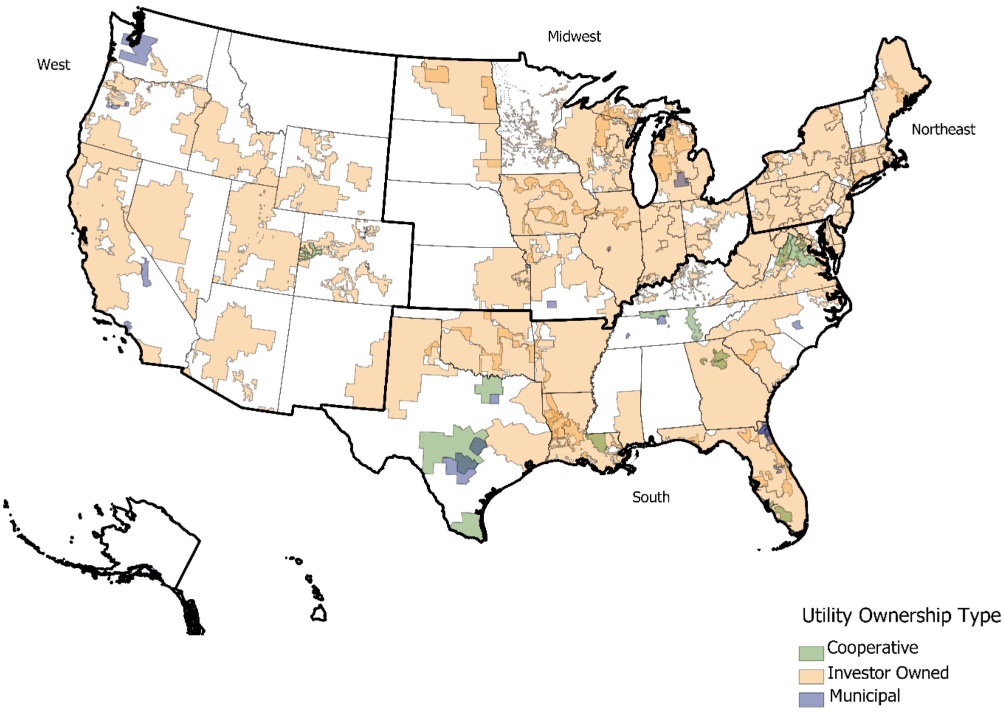


Figure 47. Utility territories that have compensation mechanisms in the subset of URDB data used within this study. Territories are marked according to the legend. Darker shades represent territories with utility overlaps, and white spaces indicate territories with no available data.



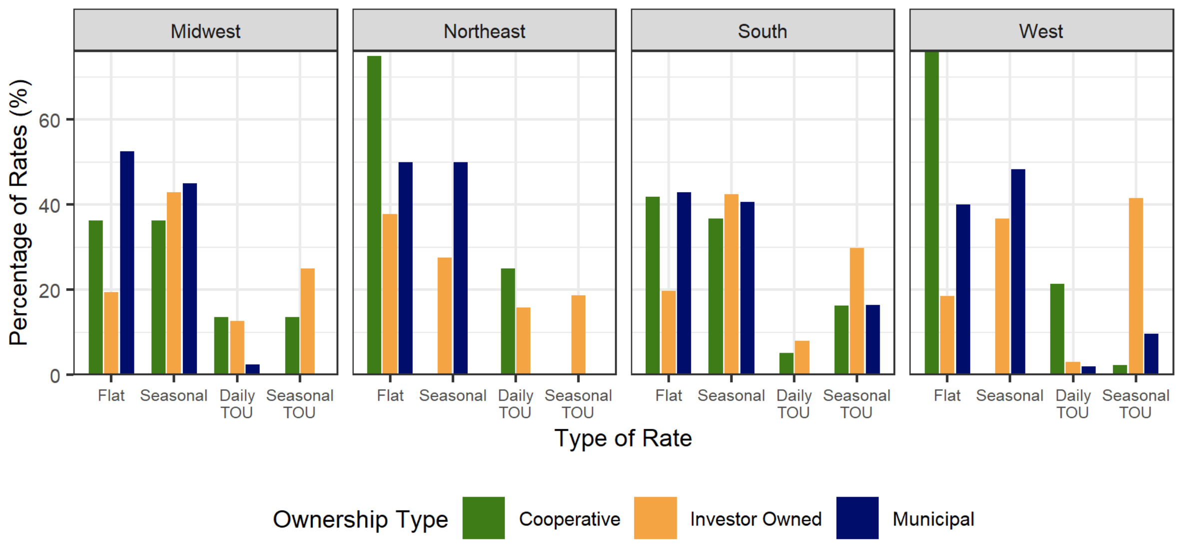
Results

Rate Structures

Across regions and utility ownership types in the United States, flat and seasonal rates remain prevalent, as shown in Figure 3. The perception that customers do not understand or will not respond to TOU rates has historically deterred regulators and utilities from adopting these rates [21], which largely appears to persist in the current landscape. Investor-owned utilities are more likely to offer TOU rates over municipal or cooperative utilities, and when investor-owned utility rates vary by time of day, they are most likely to also vary by season as well. This signals that successful TOU pilot programs are providing investor-owned utilities with cost savings that are both valuable in their business model and supporting grid operations, increasing TOU offerings within this utility type. Such rate structures prompt demand-side behaviors that GEBs are well-suited to provide, allowing the grid to benefit and customers to realize the potential of increased flexibility in their homes.

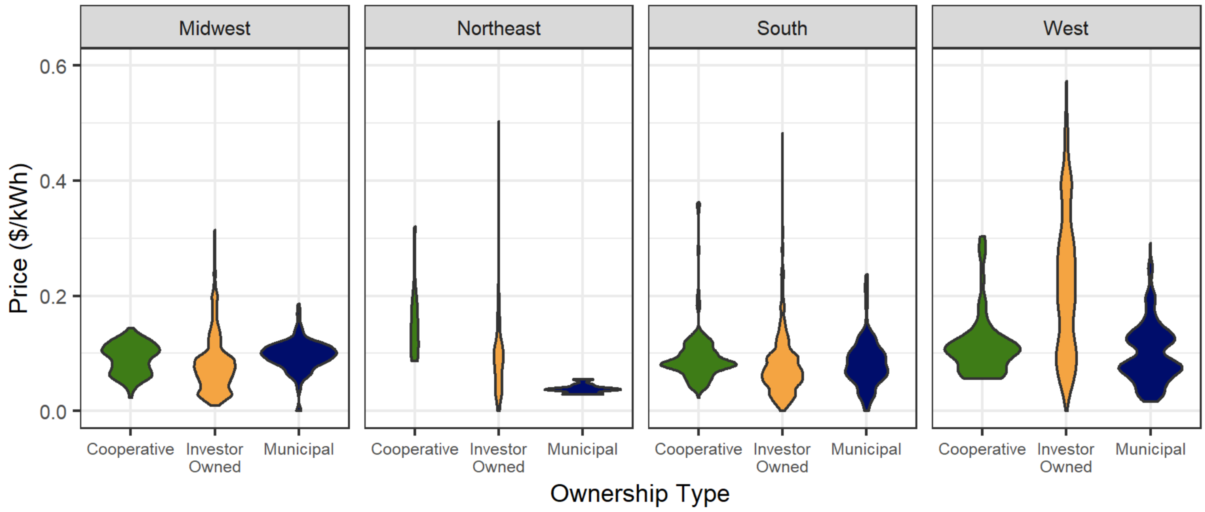
With the exception of the Northeast, investor-owned utilities are most likely to offer seasonal rates over flat rates when the rate does not vary by the time of day. Cooperative utilities, in comparison, tend to favor flat rates over seasonal rates in the Northeast and West, with flat rates and seasonal rates nearly equally as likely in the Midwest and South. Municipal utilities have few rates that vary by time within the dataset and instead favor flat and seasonal rates to a similar degree across regions. In the absence of TOU rates, GEBs will have no incentive to change the energy behaviors within a residential building, and the potential they hold to mitigate daily peaks will go untapped.

Figure 48. Types of rates across regions and utility ownership types.



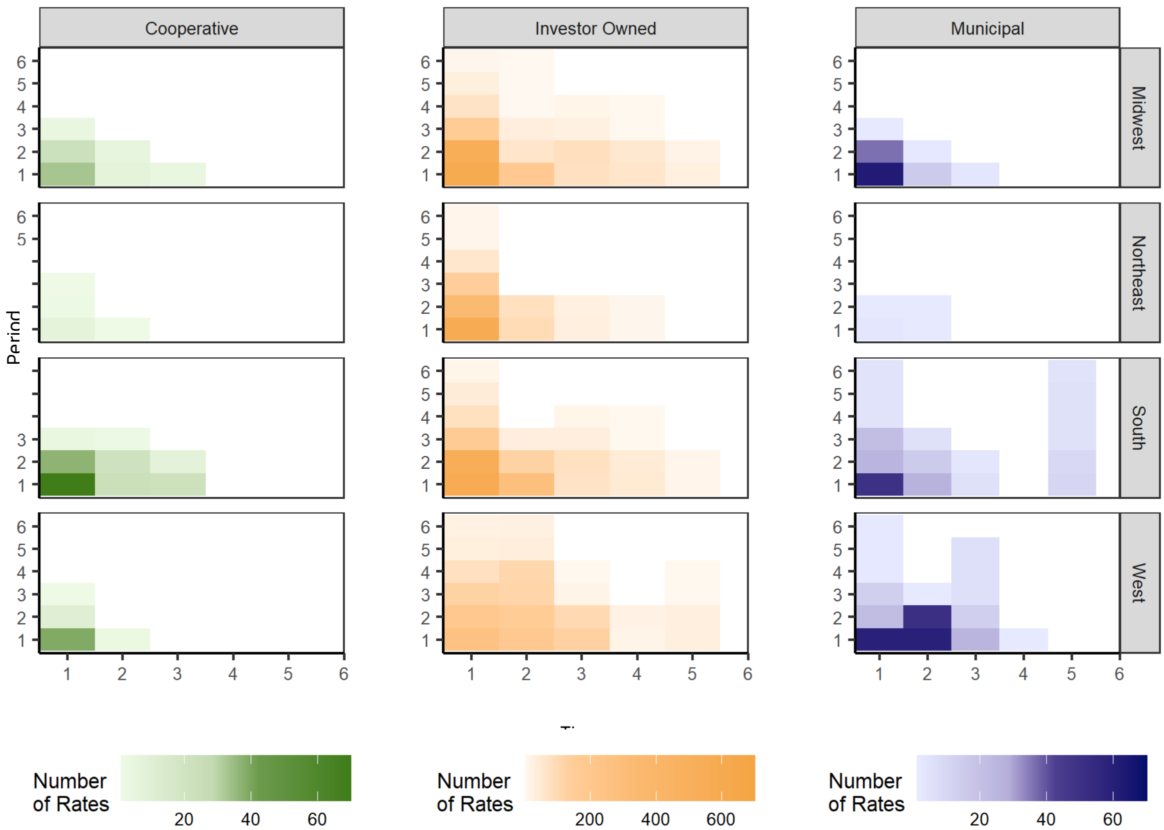
While there are a range of prices within different utility types in each region, the prices charged for energy consumption display stronger similarities across regions than utility ownership type as illustrated in Figure 4. Prices in the West are notably higher than other regions, which is particularly visible through the distribution of prices at investor-owned utilities. Investor-owned utilities in the West also have the widest range of prices, likely due to differences in generation sources seen in Hawaii and Alaska compared to hydropower in the state of Washington. Cooperatives in the South show concentrated rates slightly less than $0.12 per kWh while investor-owned and municipal utilities appear to have slightly lower prices in this region overall. Investor-owned utilities in the Midwest offer slightly lower prices than cooperative and municipal utilities. The small sample size in the Northeast shows a wide range of prices for cooperative and investor-owned utilities with municipal utilities having more concentrated prices. Given that GEBs incorporate many technologies, the magnitude of electricity prices can influence the cost-effectiveness of such investments, and increased energy efficiency can result in notable savings on energy bills for customers.

Figure 49. Distribution of energy prices in all tiers and periods within rates across regions and utility ownership types.



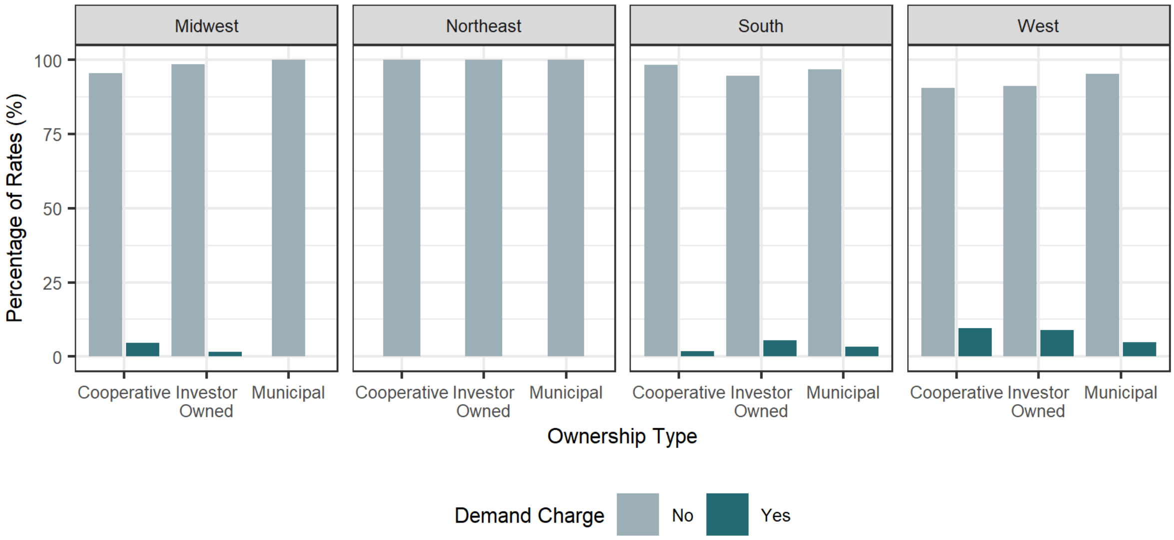
Tiered rates remain limited across the country as shown in Figure 5. Most rates contain only one or two periods with one tier within them. One exception is seen with municipal utilities in the West where two tiers are dominant in both the first and second periods of rates. This is unlikely indicative of a larger trend within the industry but reflects the tiered rates that were once prevalent in California, particularly among investor-owned utilities, which have since been replaced by TOU rates. Rates with one or two periods and a single tier within them remain prevalent across regions and types of utility ownership. In the absence of tiers, GEBs may not prioritize technologies or building structure upgrades that decrease the overall consumption of energy since there is less incentive to do so. Focus may instead shift to other aspects of the rate structure through which savings can be realized.

Figure 50. Heat map of the number of tiers within each period of the evaluated rates.



Demand charges also remain limited within the residential sector. Figure 6 indicates that utilities in the West are most likely to levy demand charges overall, and investor-owned utilities are most likely to do so in that region. While Figure 6 reflects the rates within the subset of data evaluated in this sample, thus showing a true representation of the data, the limited number of reported demand charges may not reflect an entirely accurate one. For example, while no demand charges are identified in the Northeast, a limited number of demand charges may indeed be levied. Overall, however, the likelihood of a rate having a demand charge is small. While demand charges can prompt end-users to shift their load to decrease the maximum amount of power they require during a billing cycle, the use of TOU rates to prompt that behavior appears more prevalent within the residential sector at this time. The absence of demand charges is likely to influence the way in which GEBs optimize energy consumption within a building, not needing to prioritize a decrease in peak load to avoid such charges.

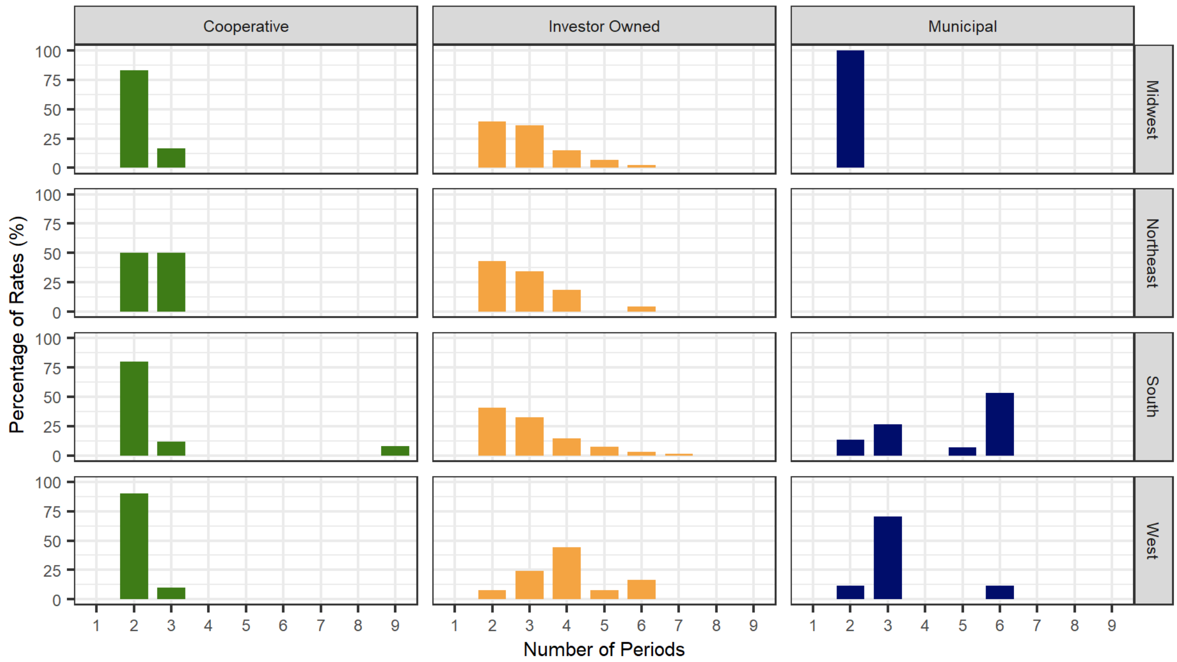
Figure 51. Prevalence of demand charges in electricity rates across regions and utility ownership types.



When electricity rates vary by time of day, they contain more than one period. The number of periods in those schedules can differ depending on what the utility sees as the primary grid needs. Most rates only contain two periods as seen in Figure 7. Except for the West, investor-owned utilities see a steady decline in the likelihood in number of periods within a rate, indicating that two periods in each day—one peak and one off-peak period—are sufficient to meet existing grid needs. Given that Figure 3 shows a prevalence of seasonal TOU rates, it is likely that these utilities have a combination of two periods during the summertime and switch to a single period in the winter. Rates with four periods are most common for investor-owned utilities in the West, showing increased complexity in the rate structure. This, along with the results in Figure 3 indicate that there are both seasonal and daily grid needs in the region that are being considered, likely resulting in TOU rates that have two periods in each day that switch in the wintertime versus summertime. Two periods within TOU rates at cooperative utilities remains most likely across regions. No unique trends are identified for municipal utilities.

The number of periods within a schedule will influence how GEBs optimize energy consumption across building technologies. With more periods, the GEB may need to become more active in shifting consumption to realize cost savings. Fewer periods within a rate, or rates with two or more periods that are only available during part of the year, suggest GEB capabilities are not needed to support the grid year-round and would likely only generate savings on energy bills during seasons when those capabilities are incentivized.

Figure 52. Number of periods within TOU rates



Even when two rates have the same number of periods, they can differ in how they are implemented within the rates' schedules. The most frequently occurring schedules in each region are shown in Figure 8 and Figure 9. Most rates have one period spanning several evening hours and another rate that covers the remaining hours of the day during weekdays. Sometimes, as is seen with the West and the Northeast, the schedule may remain the same over the course of a year with respect to the time of day but the periods within the schedule change. This reflects a change in price by season. Also common across regions and utility types are weekday rates that are flat in the winter but have daily variation in the summer months, showing the increased constraints that occur such as cooling needs. Weekend schedules for TOU rates most often do not contain variation in charges throughout the day as shown in Figure 9. The time varying schedule instead takes place during the weekdays. Flat seasonal rates are also common on weekends across regions. These schedules ultimately influence the shape of the load that GEBs create and impact the overall profits that occupants can realize.

Figure 53. Top three weekday TOU schedules by region. Each cell is broken into 24 blocks, displaying the schedule for a weekday in the associated month.

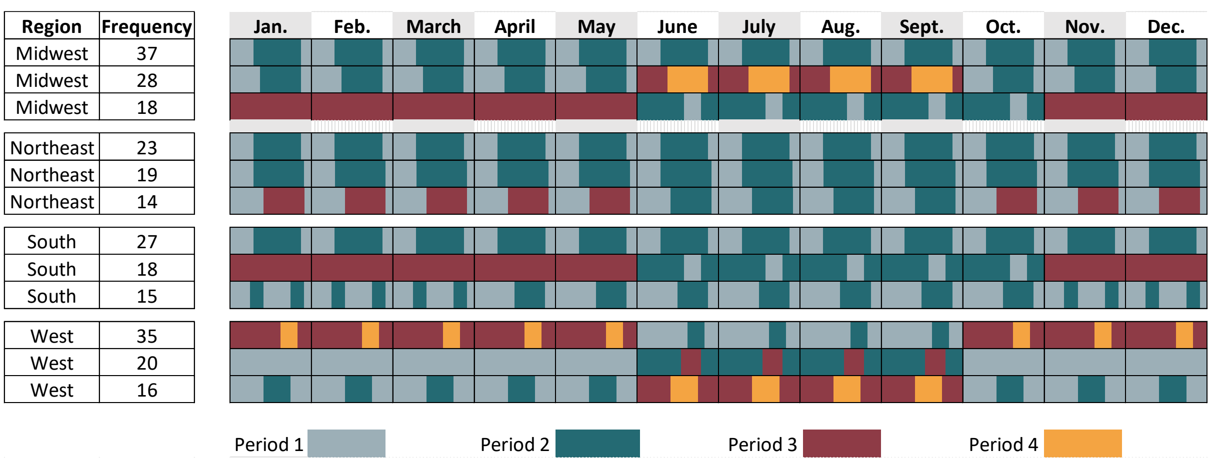
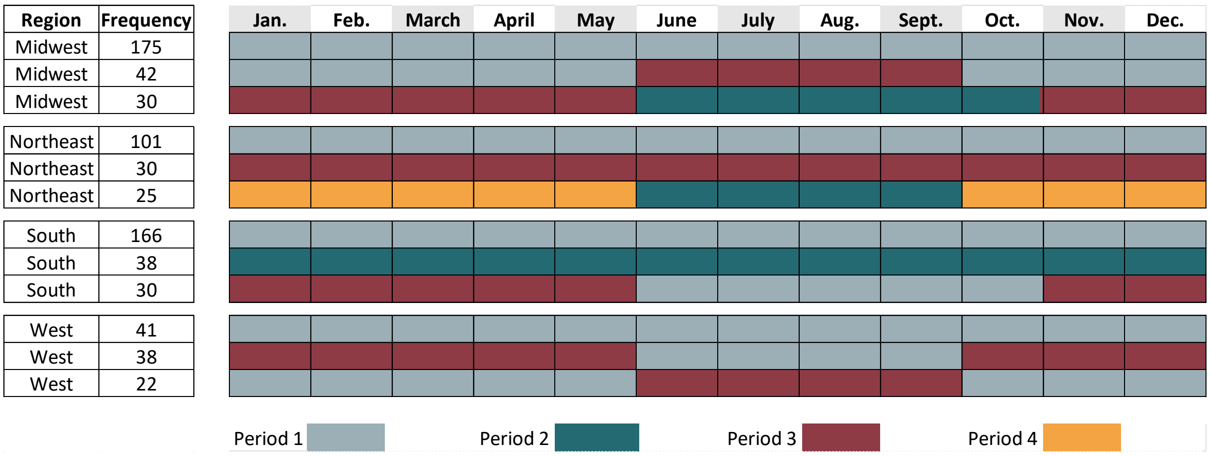


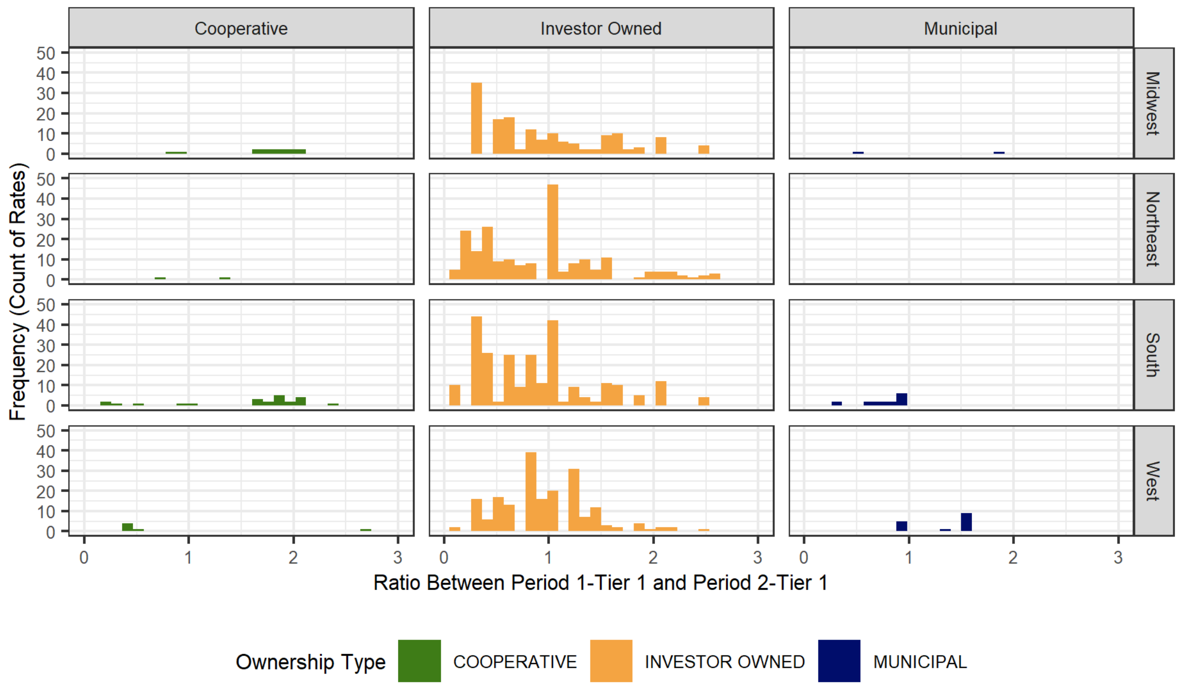
Figure 54. Top three weekend TOU rate schedules by region. Each cell is broken into 24 blocks, displaying the schedule for a weekday in the associated month.



Given that most TOU rates contain only two periods and tiers remain limited, Figure 10 shows the ratio between the price charged within the first tier in the first period and the first tier in the second period of TOU rates. This ratio shows the relative difference in prices charged during each period. The closer the ratio is to one, the less of a price differential. For residential buildings to adopt GEB technologies that increase their flexibility, greater price differentials result in greater savings.

The sample sizes for municipal utilities and cooperatives are small, with no distinguishable trends identified in the ratio between these two periods. The rate in period two of TOU rates in investor-owned utilities is often higher than that of period one. Western and Northeastern investor-owned utilities see most rates with a ratio that comes close to one, indicating there is little difference between the prices in the different periods. The investor-owned utility rates in the Midwest and South are most likely to have a ratio less than one but often not less than 0.5, indicating that the difference between charges remains limited.

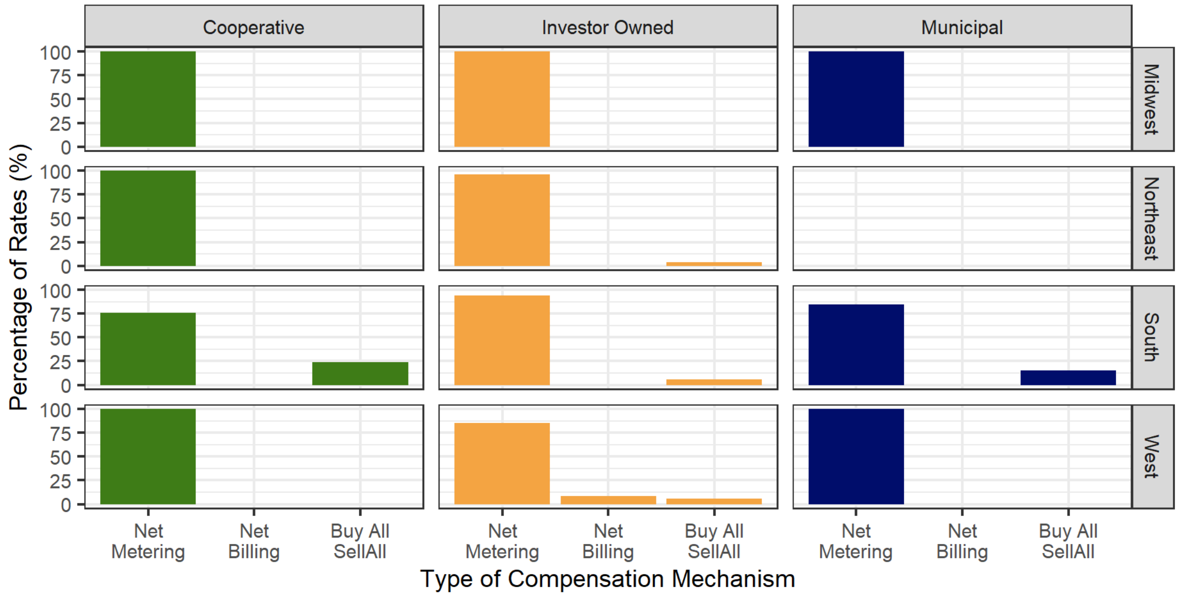
Figure 55. Ratio between energy charges in period one, tier one and period two, tier one.



Compensation Mechanisms

Compensation mechanisms across the United States are dominated by net metering. However, buy all-sell all mechanisms have a small presence in the South and in investor-owned utilities. Investor-owned utilities in the West are most likely to offer a compensation mechanism other than net metering, but that likelihood remains low. Net billing is only documented in Western investor-owned utilities in this dataset. While the export rates were not explicitly considered in this study, the emergence of net billing and buy all-sell all mechanisms at investor-owned utilities may reflect the growing industry trend to move beyond classic net metering, which often compensates exports at the retail rate, to new mechanisms that better reflect the actual utility value realized through that exported electricity. A decrease in export rates may further incentivize GEBs that have onsite generation to prioritize self-consumption, shifting load accordingly to do so. Batteries may also become a higher priority within these scenarios and change the optimization algorithm for the GEB. A discussion of these results and their broader implications are provided in the next section.

Figure 56. Prevalence of compensation mechanisms across regions and utility ownership types.



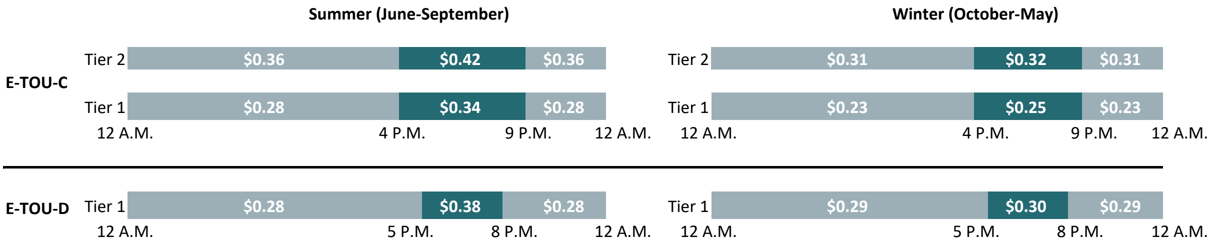
Discussion

Flat and seasonal rate structures remain dominant throughout the United States, both geographically and from a utility ownership perspective. While much of the technical work to date around GEBs has relied on TOU rates to monetize flexibility and energy efficiency from buildings, those rate structures have yet to infiltrate utility policies. The limited use of TOU rates, tiers, differences in prices charged between periods, and demand charges all restrict the potential of GEBs to provide value to the grid or their occupants to realize cost savings for their energy efficiency or flexibility. Electricity rates largely do not incentivize the capabilities that GEBs possess. Furthermore, net metering remains the dominant compensation mechanism. Emerging literature suggests that the rate at which customers are paid for exporting electricity under net metering is beginning to decline [22] and other available compensation mechanisms make it more valuable for customers to consume the electricity they produce rather than to export it. Such a trend could influence technology adoption and change the way in which GEBs optimize their energy consumption, prioritizing self-consumption.

Of all the regions and utility types considered in this baseline, Western investor-owned utilities may serve as a favorable market for early GEB adopters, given the current landscape of electricity rates there including seasonal TOU rates with schedules that often have multiple periods within each day, year-round and higher electricity prices that could make technology adoption more cost effective. However, the minimal differences in price between the periods could create delays in technology adoption if payback periods are insufficient. The structures themselves could still promote energy behaviors that result in better conditions for the grid without creating comparable cost savings for the end user. Take for example two residential TOU rates offered at Pacific Gas & Electric in California, which recently shifted to default all residential customers to

TOU rates [23]. Rate E-TOU-D is a seasonal TOU rate with one tier following the schedule in Figure 12, and E-TOU-C is a seasonal TOU rate with two tiers where the second tier is triggered after a baseline allowance of energy consumption has been surpassed. The schedule for E-TOU-C is followed every day, and the TOU schedule for E-TOU-D is only followed on weekdays with the weekends charging the Period 1 rate every hour.

Figure 57. Schedules for two TOU rates at Pacific Gas & Electric. Adapted from [23].



A customer considering GEB technologies that could shift building loads might look at potential cost savings under these two options. Consider the monthly bills for a building in Sacramento whose load profile for June 1st is shown in Figure 13 alongside the resulting load profile when that building shifts 30% of its load away from the peak periods in each rate to the lowest point of consumption during the day. The shift in consumption changes the customer's bills over the course of the year.

Figure 58. Energy load for a representative home in Sacramento, CA on June 1st.

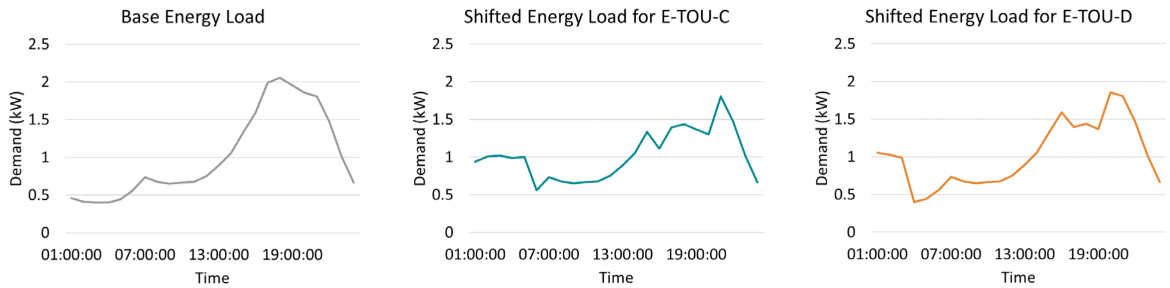
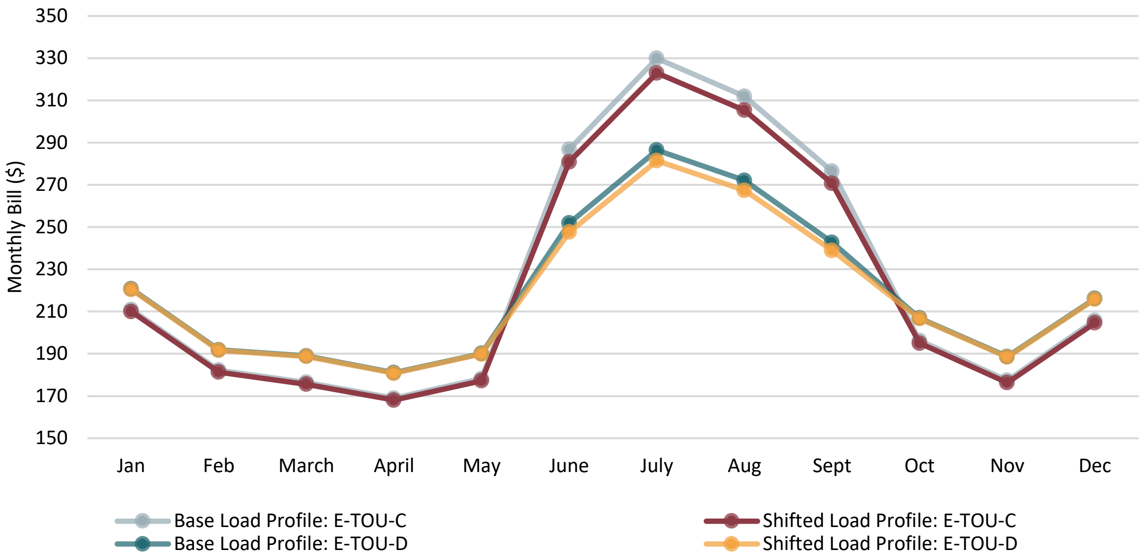


Figure 14 shows that shifting load results in slightly lower monthly bills during summer months. The annual costs under the baseline consumption for rate E-TOU-C are $2,701, and shifting load under this rate brings the annual charges to $2,668. Under rate E-TOU-D, annual costs are $2,637, and shifting the load results in annual charges of $2,617. Neither rate offers significant savings for the representative home, but the structure of the rate through the tiers and periods is designed to promote both energy efficiency and flexibility within building loads. The mismatch between value generated for the grid and cost savings for the customer may eventually pose challenges for widespread GEB adoption.

Understanding the current landscape of utility policies will help create the transition from the current stock of buildings to a future populated with GEBs. Since existing utility policies largely do not incentivize a change in behavior over the course of a day or billing cycle, building technologies are not likely to prioritize these behaviors at-scale, leaving potential cost savings and grid benefits on the table. To what degree are TOU rates necessary to generate this behavior? How significant must customer savings be to incentivize technology adoption and energy efficiency upgrades? In places where TOU rates are becoming more prominent, to what extent have behaviors changed, and what characteristics of the utility and customer enabled this change?

Figure 59. Monthly bills for a home in Sacramento under TOU rates at Pacific Gas & Electric before and after shifting peak load.



The sensitivity of these policies, how they may evolve over time, and quantifying the influence they have on GEB adoption and integration is reserved for future work. Future work will address the other customer segments as well, including commercial and industrial.

Limitations

While this work provides a baseline of electricity rates and compensation mechanisms in the United States, the analysis is limited to an open-source dataset that does not offer complete coverage across the country. It strongly favors investor-owned utilities, which only make up 6% of the utilities in the United States. However, investor-owned utilities serve more customers than any other type of utility, providing service to 72% of the customers in the country [20], thus still offering a baseline for most customers in the United States. More comprehensive data reflecting other types of utilities besides those that are investor owned should supplement this baseline.

Furthermore, the dataset is severely restricted in the sell rate of electricity back to the grid, limiting this study solely to a categorization of compensation mechanisms. Given the emerging trend where net metering compensates customers at less than the retail rate, insights into these trends are important to understand. Only a high-level assessment of the categories of compensation mechanisms were possible within this study. Ultimately this study shows trends across the country, but electricity rates and compensation mechanisms remain highly specific to their utility and those details remain significant for site-specific analyses.

Conclusion

GEBs integrate energy efficiency and flexibility to benefit both their occupants and the electric grid. To realize their widespread adoption, utility policies must support the behaviors needed to build a resilient grid that integrates high levels of renewable energy. This work baselines both the utility rate structures and compensation mechanisms in the United States, highlighting the current landscape and how it could interact with widespread GEB adoption and operations. Tiered rates that promote energy efficiency and TOU rates that promote energy shedding and shifting remain limited within the residential sector, but Western investor-owned utilities have many rates that could support both the operation of GEBs and technology adoption to create them. With net metering remaining the most prevalent form of compensation mechanism and the rate of compensation under this mechanism declining, GEBs with onsite generation could prioritize self-consumption in their operations. Utility policies are often slow to change, but their evolution will need to dovetail with increased efficiency and flexibility within the residential sector to support GEBs both in the adoption of technology and daily operations.

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10 APPLIACES AND LIGHTING

Making The Case For Saving Water and Energy Through Increased Ownership And Proper Use Of Dishwashers

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Abstract

Residential dishwashers are an energy and water efficiency success story. Using 53 percent less energy than they did in the 1990s, residential dishwashers are highly efficient, while also offering consumers good cleaning performance. Because residential dishwashers in the United States (U.S.) have been subject to several rounds of increasingly stringent energy conservation standards and ENERGY STAR criteria, opportunities for continued cost-effective savings without negatively impacting product performance are declining. Nonetheless, there are still additional water and energy savings to be gained related to dishwashing. Dishwashers not only have a low penetration in U.S. households, but they are also the most underused major appliance in the U.S., meaning that many households still hand wash their dishes, using enormous amounts of water and energy as compared to cleaning dishes in the dishwasher. Even households that own dishwashers either do not use them or pre-rinse their dishes before loading them in the dishwasher, wasting significant amounts of water and energy. Thus, there are significant savings opportunities to be achieved by increasing dishwasher ownership in the United States and encouraging those who own dishwashers to use them in a way that minimizes water and energy use. The opportunities for savings attributable to owning and using a dishwasher are perhaps the largest in traditionally underserved communities, such as low-income households.

Residential Dishwashers Are An Efficiency Success Story

Manufacturers and United States (U.S.) regulators can claim success in helping to drive the development of high energy and water-efficient dishwashers. Manufacturers strive to improve efficiency to meet consumer demand and their own individually established sustainability goals. Regulatory drivers are also part of the history of improving unit energy consumption for residential dishwashers.

Residential Dishwashers Have Long Been Regulated In The United States

Through the Appliance Standards Program, the U.S. Department of Energy (DOE) has long regulated residential dishwasher energy and water efficiency—dishwashers have complied with energy conservation standards since 1988.

Residential dishwashers in the U.S. have been subject to four energy conservation standards to date. The Energy Policy and Conservation Act of 1975, as amended (EPCA) required residential dishwashers to be equipped with an option to dry without heat. Then, in 1991, DOE issued the first energy performance standards for dishwashers, compliance with which was required in 1994. The next amended standards for dishwashers were required in 2010. Energy conservation standards for residential dishwashers were again amended in 2012 and compliance with those standards was required in 2013. Those standards result from a negotiation and petition submitted to DOE in 2010 by groups representing manufacturers (including the Association of Home Appliance Manufacturers, or AHAM), energy and environmental advocates, and consumer groups.

That is not the last time DOE evaluated whether further amended standards for dishwashers in the U.S. are technically feasible and economically justified for consumers and manufacturers. In 2016, DOE concluded that amended energy conservation standards would not be economically justified at any level above the standards set in 2012, and, therefore, decided not to amend standards. Notably, DOE has a current rulemaking open to assess—as it is required to do by law—whether amended standards are now justified. [1].

Mandatory minimum energy conservation standards are not the only regulatory driver for improved dishwasher efficiency. The ENERGY STAR program—first administered by DOE for home appliances and now by the U.S. Environmental Protection Agency (EPA) in partnership with DOE—also sets energy and water efficiency targets for residential dishwashers. In fact, there have been six ENERGY STAR specifications for dishwashers since 1996. Each specification strives to push the market toward more efficient products. Although the ENERGY STAR program does not set mandatory standards, ENERGY STAR qualification has essentially become mandatory in the marketplace as is demonstrated by particularly high penetration of

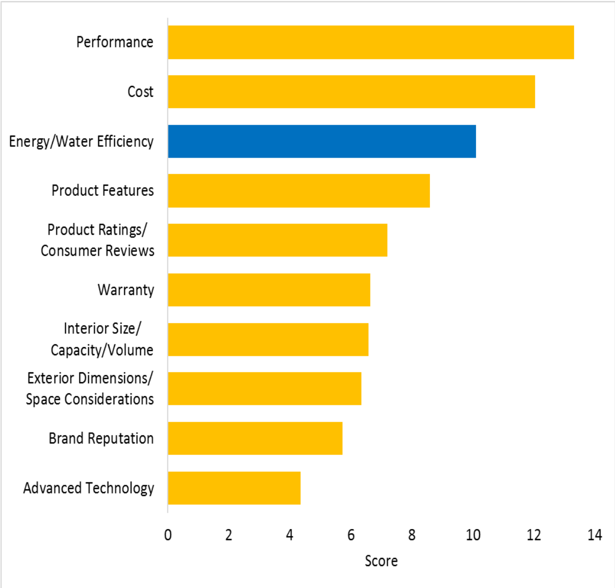
ENERGY STAR certified dishwashers. Most residential dishwashers are certified to ENERGY STAR Version 6.0 (current ENERGY STAR)—close to 90 percent of dishwashers shipped for sale in 2019 were ENERGY STAR certified. [2]. In 2020, nearly all dishwashers shipped for sale were ENERGY STAR certified. [3]. In order to meet the current ENERGY STAR specification, standard-sized dishwashers must meet an Annual Energy Consumption (AEC) of less than 270 kilowatt-hours per year and maximum water consumption of 3.5 gallons per cycle. For compact dishwashers, the maximum AEC is 203 kilowatt-hours per year and the maximum water consumption is 3.1 gallons per cycle.

Residential Dishwashers Are Incredibly Efficient

Energy and water efficiency gains for dishwashers are dramatic and undeniable. A typical new dishwasher uses 53 percent less energy than a typical 1990 model. [4].

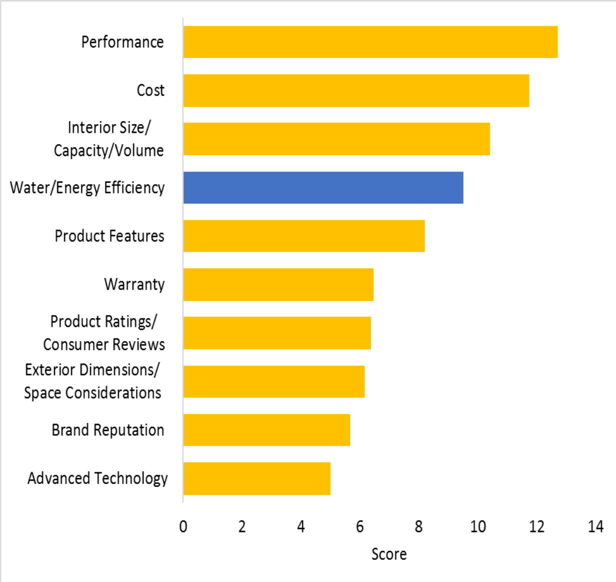
Consumers value efficiency and water savings for dishwashers even more than for other products, so long as efficiency criteria are not pushed to its extreme. According to a 2010 study done by Bellomy Research for AHAM, energy and water efficiency ranked as the third most important purchase decision criteria, following performance and cost in the top two spots. (For other major appliances, water and energy efficiency ranked fourth, after interior size/capacity/volume).

Figure 1. Top Purchase Drivers For Residential Dishwashers



Thus, increased efficiency is important to consumers, so long as it does not negatively impact cost or product performance.

Figure 2. Top Purchase Drivers For Other Major Appliances



Opportunities For Additional Energy And Water Savings Via Improved Product Efficiency Are Diminishing And Risk Negative Performance Impacts For Consumers

Opportunities for additional energy and water savings beyond those already achieved in residential dishwashers are severely diminished as products are nearing maximum efficiency under available technology. Additional cost-effective efficiency gains are not yet widely available beyond the current ENERGY STAR criteria without sacrificing performance and product functionality. As discussed above, residential dishwashers have already been subject to several rounds of increasing energy and water conservation standards, and therefore limited gains are available in energy and water savings. Energy and water savings potential at this stage are more likely to come at the expense of performance and design features than they were in the past. Note that this does not mean that there are not any dishwasher models that can achieve higher levels of efficiency and maintain product performance. Such products may come at a higher cost to consumers and a broad range of products and model platforms may not be capable of achieving these efficiency levels.

Certain elements of wash performance must be maintained to ensure product functionality. For example, the wash temperature must be warm enough to activate the detergent, otherwise the dishwasher will lose its utility. The dishwasher must provide water at 120-140 °F (49-60°C) to break up surface oils and fats to avoid leaving residual film buildup. [5]. This is a critical point because water heating is the biggest contributor to energy use regardless of manufacturer. Once water heating reaches its minimum, manufacturers resort to lengthening cycle times substantially in order to maintain cleaning performance.

AHAM conducted testing that demonstrates how energy conservation standards or ENERGY STAR efficiency criteria beyond the current ENERGY STAR levels would negatively impact performance. [6]. For this testing, AHAM investigated its concern that increasingly stringent energy conservation standards would negatively impact performance by making it more difficult for dishwashers to remove adhered soils and grease, therefore resulting in buildup over time on the dishes. This would not be revealed by a single performance test using the ENERGY STAR performance test procedure. Thus, AHAM members conducted the ENERGY STAR performance test, with slight variations. One set of testing focused on grease and buildup over time. The second set of testing focused on adhered soils and particulates. The ENERGY STAR performance test does not evaluate these areas. The test upon which it is based—ANSI/AHAM DW-1-2010—is meant to measure the redisposition of soils and, thus, uses soils best suited for that purpose. Consumer panels were asked to comment on the cleanliness of the dishes at the existing DOE standards levels as well as more stringent levels.

For the first set of testing, which focused on grease and buildup over time, the consumer feedback showed that consumers generally accept the performance of dishwashers meeting existing energy conservation standards, but some do have performance concerns. This is true across dishwasher brands. Conversely, consumer feedback on the levels DOE was analyzing, which were more stringent than current ENERGY STAR levels, was overwhelmingly negative. Commenters stated that the dishes seemed dirty and unsanitary and that consumers could see grease on them and would not eat off them.

For the second set of testing, which focused on adhered soils and particulates, consumer comments again revealed that consumers generally accept the performance of dishwashers meeting existing energy conservation standards, but do have some concerns with performance. This sentiment is also true across dishwasher brands. The results were, however, overwhelmingly negative at the considered 234 kWh/year and 3.1 gal/cycle efficiency level, with consumers stating that the dishes were unsanitary, unappetizing, filthy, and gross. This demonstrates that increased efficiency standards or ENERGY STAR criteria beyond current ENERGY STAR levels would likely have negative results for consumers.

Although cleaning performance is a key element of dishwasher performance, it is not the only one. Other performance elements important to consumers that are at risk at energy conservation standards levels beyond the current ENERGY STAR levels are cycle time, drying performance, and noise level. To be consumer relevant, several elements of performance must be evaluated. The dishwasher is a holistic system—changes in one area impact other areas.

The washing process, and ultimately wash performance, is a function of washing temperatures, length of washing cycles, types and amounts of detergent applied, and mechanics (power). [7]. These four factors all impact each other. Decreasing one factor, like energy or water, means that the other factors, such as time, need to increase. The key point is that in order to reduce energy and water use and maintain cleaning performance, it is likely that cycle time would reach a level unacceptable to consumers. In 2015, based on a survey AHAM conducted of its members, the shipment weighted average normal cycle time was 1.76 hours. According to 2019 data AHAM collected from its members, with most dishwashers being at more efficient levels than in 2015 (current ENERGY STAR), shipment weighted cycle time was 2.02 hours, which is a 14.8 percent increase from 2015. Further increasing the stringency of standards or ENERGY STAR criteria would likely dramatically increase cycle time, likely to three or more hours. This is supported by the fact that, under the most recent European Union Ecodesign compliant dishwashers have long cycle lengths, ranging from 3.25 hours to nearly five hours. [8].

Moreover, as discussed further below, at energy conservation standards or ENERGY STAR criteria beyond current ENERGY STAR levels, consumer behavior is likely to change. If the performance of the normal cycle is negatively impacted, consumers might be more likely to select cycles or options that use more energy and water instead of the normal cycle, which is the energy test cycle in the U.S. In addition, as a "rebound effect," consumers could choose to run the dishwasher more than once to reach the desired level of cleanliness and/or pre-rinse dishes before placing them in the dishwasher, both of which would negate projected energy savings from increasing standards. Worse yet, they could choose not to use the dishwasher at all.

For all of these reasons, to continue achieving energy and water savings related to dishwashing, a new approach other than continuing to increase the stringency of energy conservation standards and ENERGY STAR criteria for residential dishwashers is needed.

Environmental Justice: Excessively Stringent Standards Will Have Additional Negative Consumer Impacts

Disproportionate And Negative Impacts On Low-Income Consumers

A typical lifecycle cost analysis demonstrates that energy conservation standards beyond the current ENERGY STAR efficiency level are not economically justified. Perhaps more importantly, focusing on low-income consumers and underserved communities in the United States shows that energy conservation standards beyond the current ENERGY STAR level will negatively and disproportionately impact those consumers. This disproportionate impact raises significant environmental justice concerns.

Based upon AHAM's review of DOE's Compliance Certification Management (CCMS) database, a majority of the most energy-efficient models in the CCMS database are no longer widely available through retail channels or are for niche groups of consumers. A comparison of AHAM shipments to DOE's CCMS model counts by efficiency level show a significant difference between models being shipped for sale on the market today versus what is required to be listed in CCMS.

These data show that shipments are concentrated at the current ENERGY STAR level and that there are very few shipments above that. The lack of shipments with respect to more efficient dishwashers means that significant investments are required in order to comply with amended energy conservation standards above the current ENERGY STAR level. These investments are unlikely to be balanced by significant energy savings at higher efficiencies, as savings are greatly diminished for this product category as discussed elsewhere in this paper.

As governments investigate increasingly stringent standards for dishwashers, they should be aware that in instances where a significant number of consumers will bear a cost, that burden will likely fall disproportionately on low-income consumers. As a matter of environmental justice, it is inappropriate to concentrate the negative impacts of energy conservation on these low-income households. In the United States, doing so is inconsistent with Executive Order 13985, "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government." This Executive Order, issued during President Biden's first days in office, requires federal agencies to assess whether its programs and policies perpetuate systemic barriers to opportunities and benefits for people in underserved communities such as persons adversely affected by persistent poverty or inequality. Rather than using the blunt instrument of minimum standards which could inadvertently concentrate the economic burdens on these disadvantaged communities, governments should investigate non-regulatory approaches to achieve water and energy savings without creating this undue burden, as discussed more fully below.

Lower-income consumers cannot pay more for a more efficient dishwasher and assume they will get a payback over time on their energy or water bill. The alternative will likely be that these households will change their purchase decisions rather than move to higher-priced products. Some consumers may purchase the more expensive products, but will incur substantial debt to do so. Others who cannot afford to purchase a new appliance may instead either purchase a used, less efficient appliance, or—more likely given the low penetration of this product in homes—forego what is seen as a discretionary purchase and, instead, hand wash their dishes. Their economic decision-making will likely result in spreading out a series of lower-cost decisions rather than making a single large purchase. The effect of this choice is the use of significantly more water and energy, which is contrary to the goal of amending energy conservation standards. These consumers will spend more money on their water and electricity bill than other population segments, which is contrary to environmental justice goals. These consumers would benefit most from an energy-efficient dishwasher that can save them energy, water, money, and time.

According to the U.S. Energy Information Administration (EIA), 2015 Residential Energy Consumption Survey (RECS 2015), only about 67 percent of U.S. households have a dishwasher. This is also supported by consumer research AHAM conducted in 2015, which shows that only 64 percent of U.S. households own a dishwasher. This penetration decreases even further when examining households by gross income level—low-income consumers are far less likely to own and use a dishwasher than the average population, as shown below.

Table 1. Dishwasher Ownership And Usage By Income Level

Dishwasher Ownership	Less than $20K Gross Household Income	$20K – $39K Gross Household Income	National Average
Owns a dishwasher	37.1%	58.8%	67.3%
Owns and uses their dishwasher	23.1%	41.2%	53.9%
Annual Cycles	106	118	185

Source: Energy Information Administration's Residential Energy Consumption Survey 2015

More research is needed to understand the reason for this, but it makes sense that this product may be seen as discretionary (different from a refrigerator, for example) because handwashing is an option. That means, however, that a significant portion of lower-income populations are spending more than other consumers on their water and electricity bills due to handwashing, as discussed more fully below. These consumers are sensitive to price and will be less likely to purchase a dishwasher if prices increase because of energy conservation standards or if there are net costs to consumers as shown through life cycle cost analysis.

If governments reduce minimum energy use standards for dishwashers too much, they will shift the burden of energy and water conservation onto the population least able to pay for the additional costs and will prevent those same consumers from realizing the benefits of owning a dishwasher. Regulators need to do a much more thoughtful assessment of how ever tighter standards affect low-income households and other traditionally disproportionately affected groups. Rather than relying on a purely academic analysis, regulators need to affirmatively engage representatives of traditionally disenfranchised groups and a broad coalition of other stakeholders, including manufacturers and energy advocates, to assure the promotion of environmental justice. This further supports investigating other approaches to achieve additional energy and water savings without creating this undue burden on low-income and underserved communities. Such policies can actually help those communities.

Further, regulators should carefully assess the consumer economic effects on core subgroups:

• Low-income households, including the effects of lost time used in hand washing versus using a dishwasher;

• Rural households, including an accurate measure of the cost to the consumer of water and sewer/septic;

• Households with dishwashers that do not use them or use them only infrequently, to determine why they do not use a dishwasher and what can be done to increase dishwasher use; and

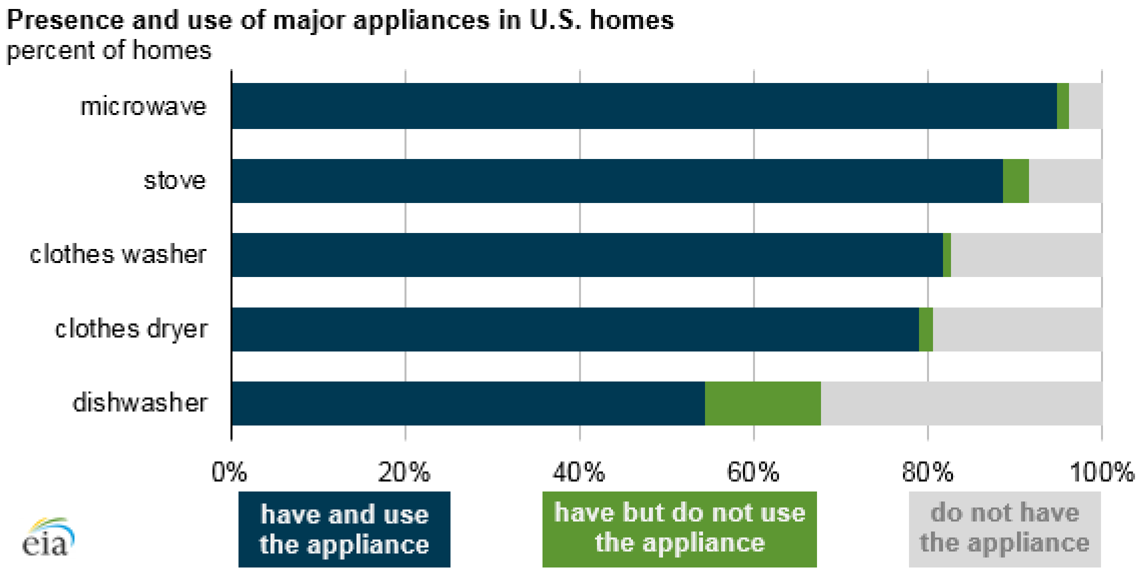
• Households without dishwashers, to determine why they do not currently own a dishwasher and what can be done to make dishwasher access or ownership possible.

Opportunities For Savings Exist Through Increased Ownership and More Frequent, Proper Dishwasher Use

Dishwashers, When Owned, Are Underused

As stated earlier, only about 67 percent of American households own a dishwasher. For those that own one, dishwashers are the most frequently unused appliance—almost 20 percent of dishwasher-owning households did not use it in 2015. In fact, according to the EIA, only about 54 percent of U.S. households both have a dishwasher and use it at least once per week.

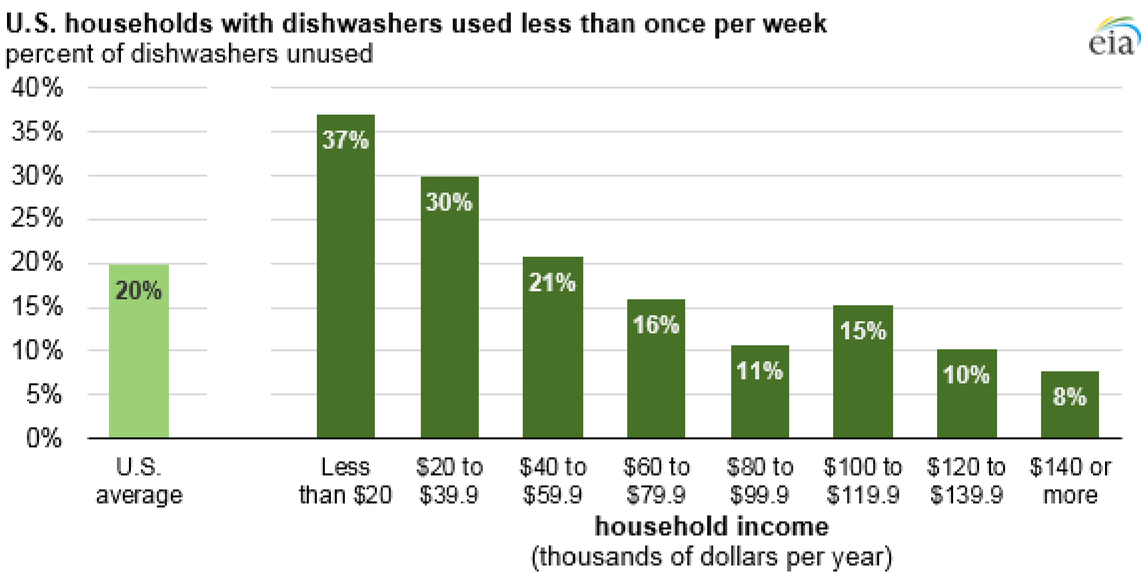
Figure 3. Use of Major Appliances In U.S. Homes



1. U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey.
2. Can be accessed at https://www.eia.gov/todayinenergy/detail.php?id=31692.

Importantly, EIA data show that lower-income households are less likely to use their dishwashers than those with higher incomes. About 37 percent of dishwasher-owning consumers with the lowest income do not use their dishwashers compared to the national average of almost 20 percent that does not use their dishwashers. In contrast, those with the highest incomes are more likely to use their dishwashers with only eight percent of dishwasher-owning households not using their dishwasher.

Figure 4. Dishwasher Use In the United States



1. U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey.
2. Can be accessed at https://www.eia.gov/todayinenergy/detail.php?id=31692.

This means that, even for the households that own a dishwasher, there are a significant number of American households handwashing all or a significant portion of their dishes.

Current Consumer Behavior Wastes Water And Energy

It is well-known and researched that handwashing and pre-rinsing waste significant amounts of energy, water, and time. Yet, consumers continue to have the misconception that handwashing takes less time or energy and/or that pre-rinsing is necessary. These misconceptions drive behavior that wastes water and energy.

As discussed above, a significant portion of American households either do not own a dishwasher or do not use it, meaning that they are handwashing all of their dishes. According to a study done by Proctor and Gamble to support their "do it every night" campaign which encourages consumers to use their dishwashers every night, a sink uses four gallons of water every two minutes, [9] while a standard dishwasher meeting current ENERGY STAR levels uses no more than 3.5 gallons in one cycle. Washing the dishes with an open tap can use up to 20 gallons of water, according to EPA. [10]. A new dishwasher uses less than a quarter of the energy used when washing dishes by hand and saves over 8,000 gallons of water per year according to EPA. [11]. Washing dishes in a current dishwasher instead of hand washing can cut utility bills by about $130 per year, [11] which is more than the average savings are likely to be from increasing standards or ENERGY STAR criteria.

Handwashing dishes wastes not only water and energy, but time and money as well. Handwashing dishes costs about $1,500 more in energy and water than using one of today's efficient dishwashers. [11]. Moreover, loading dishes in the dishwasher takes less time than cleaning and drying each item—using a new dishwasher can save over 230 hours over the course of a year. [11]

For those households that have and use their dishwashers, pre-rinsing dishes continues to be a consumer habit. According to a 2019 study, the majority of consumers (67 percent of the study participants) pre-rinse their dishes before loading them into the dishwasher. [12] This is true in other countries as well—a European study showed that almost all households with a dishwasher pre-treated their dishes before loading them into the machine. [13] According to EPA, pre-rinsing dishes can use up to 10 gallons of water before the dishes are loaded in the dishwasher. [7].

Compare these savings to the savings likely to result from further increased energy conservation standards or ENERGY STAR specification levels. According to an EPA analysis of proposed increased ENERGY STAR levels, consumers would save only about $16 annually—or $190 over the lifetime of the dishwasher as compared to a product meeting the current minimum energy conservation standards. An analysis that recognizes that most dishwashers are already at the current ENERGY STAR levels shows that energy savings resulting from an 11 percent increase in the stringency of the ENERGY STAR level for energy and an 8.5 increase in the stringency of the water efficiency requirement would save consumers a total of about $7.60 per year or just 2 cents per day, including an approximate $3.03 per year gas savings, which is kept constant. These savings—which, because of the increased cost of a dishwasher meeting these levels—would take almost the entire useful life of the product to recoup, are dwarfed by the savings opportunities available by increasing the ownership and proper use of dishwashers.

Proper Dish Cleaning Practice Should Be A Focus For Regulators

The environmental goal for dishes should be to focus on dish cleaning, as continued efficiency improvements have diminishing returns with available technology. Dish cleaning is the process of taking used, soiled dishes and preparing them for reuse. A dishwasher is a tool in that process. Focusing only on the tool in a silo, and not on the process itself, can and will easily lead to environmentally unsound policy decisions. The dishwasher is an important part of that process and increasing the ownership and proper use of dishwashers has the potential to drive enormous energy and water savings that dwarf the savings attributable to further amended standards.

Regulators should recognize the relative importance of water savings versus energy savings when setting policy for dish cleaning. Looking out over the 30-plus years DOE assumes in its regulatory framework that the electricity grid will become increasingly powered by renewable or non-greenhouse gas emitting sources. Climate change is already causing more droughts and will continue to reduce the availability of ground water and some aquifers. Therefore, conserving water is and will become the defining environmental issue for dish cleaning.

Households use a wide range of dish cleaning behavior:

1. Complete hand washing;
2. Pre-rinsing and running partial loads in a dishwasher;
3. Pre-rinsing and running full loads in a dishwasher;
4. No pre-rinsing and running partial loads in a dishwasher; and
5. No pre-rinsing and running full loads in a dishwasher.

From an environmental perspective, the preferred ordering of behaviors is the reverse: no pre-rinsing and full or partial loads in a dishwasher would ideally be the typical behavior. The water consumption in virtually all hand washing scenarios is substantially greater than any dishwasher use. Pre-rinsing also consumes substantially more water than running a dishwasher with partial loads even twice as often (every day instead of an average of 185 loads per year).

Dishwashers Play An Important Role In Continued Energy And Water Savings

Further increasing mandatory and/or voluntary energy conservation targets is not the best way to achieve cost-effective energy and water savings for dishwashers. In fact, as discussed above, energy conservation standards or ENERGY STAR levels exceeding the current ENERGY STAR criteria are more likely to continue to drive consumer behavior that increases energy and water use and disadvantages low-income consumers.

Instead, while new technologies are developed that can improve efficiency without sacrificing product performance, it is time now to claim success with regard to unit energy and water efficiency and take a new approach that leverages that success and accomplishes significant additional energy and water savings connected to the dishwashing process.

Incentivizing and encouraging consumers who do not own a dishwasher to purchase one and to use it properly will save significant energy and water. This will help governments achieve climate goals without increasing the stringency of standards beyond current ENERGY STAR levels.

Regulators Should Establish Penetration Targets To Increase Dishwasher Ownership

Currently available dishwashers are incredibly efficient and can provide significant savings compared to handwashing—it is time to leverage these highly efficient products to achieve additional savings related to the dishwashing process. This is particularly true given the low penetration of dishwashers in American homes. Thus, the opportunity is ripe for regulators—working with others such as dishwasher manufacturers, efficiency advocates, and even detergent manufacturers—to establish penetration targets to increase dishwasher ownership. Such a campaign should consider including an element that targets lower-income consumers who are often disproportionately impacted by energy policies, but stand to benefit most from policies directed at increasing dishwasher ownership and consistent, effective dishwasher use. This is an opportunity to ensure that such consumers can save a significant amount of money on their water and energy bills as compared to handwashing.

Driving Consumer Behavior Changes Can Further Increase Energy And Water Savings

Increasing the number of American households that own a dishwasher is a good start. But, this must be coupled with a robust consumer education campaign. Because consumer behavior, even for those consumers that own and use their dishwasher, continues to waste water and energy, there are significant savings to gain by educating consumers on the best use of their dishwashers—i.e., to use the dishwasher more often, not to pre-rinse, and to use the correct cycle to clean the dishes. Because misconceptions about handwashing and pre-rinsing are deep-rooted and it will be difficult to change this behavior, [9] such a campaign must be coordinated among stakeholders including government agencies, dishwasher manufacturers and AHAM, efficiency advocates, and even detergent manufacturers. And, because data demonstrate that low-income consumers are least likely to use their dishwasher if they own it, a significant focus of the campaign should include an element that targets those consumers. Doing so will not only have enormous water and savings benefits, but will also help those consumers—who most need it—save time and money.

These coordinated efforts—increasing dishwasher penetration and encouraging proper use of dishwashers—would be a win for the environment, consumers, environmental justice communities, dishwasher and detergent manufacturers, efficiency advocates, and regulators. And they will move the energy and water savings needle much further than continued, likely futile, efforts to increase product efficiencies at the expense of consumers who will likely suffer performance decline.

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Performance from SSL Lamps used in the Brazilian Residential Sector

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Abstract

Lamps with solid state Lighting technology (SSL), base type (E-27) have shown reduced useful life values, according to users' declarations. The useful life (median) was obtained from an experiment, sample with eight types of WLEDi lamps, six different brands acquired in the Brazilian consumer market. The experiment was carried out under ambient temperature. The light output was sampled throughout the experiment by using a built-in integrator photometer and reference lamps. Different patterns of light depreciation were observed. The median of the sample was evaluated at 22 % of the nominal value and that appears on the package (25 kh) of all brands of electric LED lamp, base E-27, the type that was used in the first long-term experiment, without any extra thermal or electrical stress and which ended with a total energizing period of 6.99 kh. Spectral survey of emission from lamps and transmission factor of diffusers were carried out and are also provided. The result revealed a difference between the estimated value based on the performance from sampling carried out and the declared value in a lamp that contains a national visual identification (label) of product conformity (safety and performance). The methodology presented is simple and can help to identify, within the lamp product commercialization sector and the Brazilian lighting sector, some type of non-conforming product. A second sample is being obtained, and results of initial condition assessments that have already been carried out and that are being conducted and some selected associated subjects are presented and discussed.

Keywords: SSL Technology, Inorganic White Lighting Emitting Diode - WLEDi Lamp (LED Lamp), Standard, Developing Countries, Residential Lighting, Market Surveillance, End of Product Useful Life.

Introduction

The Brazilian residential sector had electricity consumption in 2021 of 151 TWh, which represents 30.15 % of the total electricity consumption [1], with an average monthly consumption of 159.73 kWh per household [2]. According to the same survey of possession and habits [2] it was found that each Brazilian household has an average of 6.50 light bulbs, 8.5 % incandescent, 57.5 % fluorescent, 32.3 % SSL (LED), and about 1.5 % from other technologies. In the year 2022, lamps with a luminous flux of 803 to 810 lm were acquired at points of sale in Brazil for an average price of US$ 2.01 (reference April, 2022).

The conventional incandescent lamp, in the year 2016, was banned from the market in Brazil. Currently, the user with an Edison lamp holder (E-27 base) has the option: to use the single base fluorescent lamp (CFL) or the Solid State Lighting technology (SSL: WLEDi). Local users have provided faulty lamps for evaluation and reported a very short lifespan for WLEDi lamps (inorganic white LED) with base type E-27. The penetration in the Brazilian market of SSL is effective and the knowledge available to the consumer about the reliability and effects associated with inorganic LED products to provide white light is reduced. On the product packaging, there is, highlighted a kind of label called: "Energy LED lamp"; "safety and performance", in addition to data identifying the certification process, the Brazilian Label Program - PBE (registration number, certifier), luminous flux, nominal electrical power, and luminous efficiency. The manufacturing date is also considered relevant product information. The three parameters mentioned above, which are accessed on the PBE label, whose format can be observed in a regulation model for the lighting sector in different countries. Taking the European model [3], there are two groups of requirements: product information (rated power, luminous flux, luminous efficiency, the statement on light output adjustment or "dimming", correlated color temperature) and optional information: equivalence, in power, with another conventional light source such as incandescent, the lifetime statement claim (here relevant note is made: the lifetime claim is optional, must be evidence-based, and due to the long-expected lifetime of LED lamps, termed efficient, the service life requirement can demand quite long periods for verification, depending on the application applied and, consequently, it is not considered for practical purpose. The present article discusses some of the parameters mentioned above, considering the expansion of the requirements contained in the PBE label based on experimental activities results. In the first long-term experiment, carried out with six different brands of WLEDi lamps, base type E-27, acquired in the Brazilian market to reproduce the situation of a typical consumer of the residential sector, considered the necessary financial resources to purchase a set of WLEDi lamps with an Edison base (E - 27) and expectation of accessing the median life of the sample. It was an experiment to collaborate with the training of human resources (academic). In the experiment beyond the median useful life, the luminous depreciation of sample elements was provided too. The reliability of the sample was considered for the elapsed period from the experiment until we had the sample in operation (or without showing performance: abrupt fail or L_{70}). A second experiment was started this year (2021), which is also expected to be carried out after the lamps had been subjected to data collection on the initial spectral emission ("zero hours"). Figure 1 shows a radiant Spectral Power Distribution (SPD) for a WLEDi tubular and one referential, incandescent lamp (on the right side).

Figure 1. Spectral Power Distribution (SPD) survey result for the light output of a WLEDi lamp, type G-13 base (at the left side), and for an incandescent lamp (carried out in May, 2017).

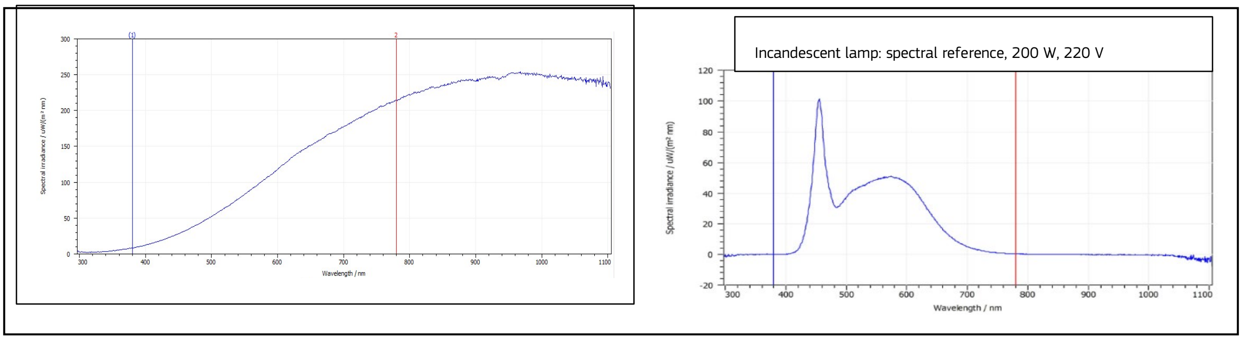


Figure 1 presents two vertical lines that delimit the so-called visible band of the electromagnetic radiation spectrum. The spectrometer used in both samples has an Instrument Systems brand, with the software called SpecWin Pro, version 3.1.1.1822, which allows the processing of spectral irradiance records with a step smaller than 1 nm. The number of brands of lamps in the sample for the second experiment is still being expanded, initially, thirty-five lamps and sixteen different brands of WLEDi lamps, base type E-27, were acquired in the Brazilian market, whose initial results were presented in an important Symposium of the lighting sector in Spain [4]. Currently, the enlarged sample is formed by forty-five lamps and eighteen brands of WLEDi lamps, now including lamps with base type G-13 (tubular). It is believed that the incorporation of as many different brands as possible can better represent groups of products in the Brazilian market. A second sampling was carried out with E-27 lamps (previously sampled), at the IEE laboratory with two G-13 (tubular LED), one CFL (Compact Fluorescent Lamp), and one incandescent lamp, to investigate the results and evaluate initial parameters and instruments performance. The results will be analyzed concerning nominal values declared on the product's body or packaging and sampled with other types of equipment with the brand Xitron and Yokogawa - YEW. The use of different instruments is intended to verify the measurement procedures used and also seeks to increase the reliability of the experimental results, in particular, harmonic distortion of the input electrical current (THDi) and power factor (PF) values. With the numerical results of some sampled lamps, provided by the laboratories of the Institute of Energy and Environment of the University of São Paulo (IEE-USP), procedures will be collated and the determination of the displacement factor (power factor of the fundamental component [5], 60 Hz) will be sought. A second parameter related to the WLEDi lamp and the power quality, in addition to the harmonic components, is the flicker for which samplings are intended after deepening and establishing the methodology. The theme is considered in the literature [6, 7, 8]. The effects of blue light on human health and possible impacts on the environment arising from the expansion of the use of SSL technology are other relevant themes for future development.

Objective

The performance of some types of lamps with SSL technology used for general lighting environments in Brazil differs from the related information contained in the product packaging. The declared useful life (L_{70}) of 25 kh, on the packaging of all products accessed, is a parameter considered relevant and that has not occurred either with a light bulb or for a sample, even considering the information like the median useful life of the sample. The hypothesis put forward is that the Brazilian market of lamps with SSL technology (LED, E-27) has products that are still quite heterogeneous, with a portion considered significant not meeting minimum technical quality requirements. The present situation suggests an investigation started. This article presents and discussed the results of the first long-term experiment carried out in the period from Dec., 2018 to Nov., 2019. Also, the initial results of the second experiment started in Jan., 2021 on the initial characteristics of lamps. According to availability and local particular prescriptions, having been conducted at the Laboratory of the Energy and Environment Institute - IEE - USP, with more sample range of WLEDi, E-27, lamps purchased at the Brazilian market. The sample has been expanded, both in brand types and in the number of proof bodies. For the second intended long-term experiment the sample was formed with 35 lamps from two classes of products, one called world and another local brand, which were considered nominal electrical power from 4.5 W to 40 W, nominal correlated color temperature (Tcp) in the 3000 K to 6500 K range. A second experimental sampling was carried out, in Nov., 2021, with five WLEDi, E-27 bulbs (already sampled previously), two G-13 base type lamps; one incandescent, and one CFL for analysis of the measurements records, statistics calculations performed are also presented. The occurrence of a possible change in the configuration of YEW equipment during part of the sampling period and estimation for the displacement factor (power factor of the fundamental component of five lamps powered at 127 V, 60 Hz) are indicated and described. To evaluate the plastic material that integrates the diffuser of the lamp, a third experiment was carried out on the transmission factor of the diffuser, which has a direct impact on the luminous efficiency of the product. Labeling and technical standards (including the topic of maximum temperature on the E-27 lamp body) are relevant topics that are considered based on the literature already accessed and experimental data collected.

Methodology

The experimental methodology was used to obtain initial characteristics such as light output from proof bodies or sample elements, relevant electrical parameters including power, electrical current, and voltage, harmonic components, power factor; light output, temperature, and median life. The bibliographic survey was carried out to search for references, in particular for the topic of labeling, and technical standards. The position of other researchers, as well as data published by another laboratory or country, is considered. Concern that was resolved from the literature collected, how the residential sector has been considered by agents in the academic world.

The first long term experiment

The report is on the long-term experiment (≥ 6000 h) conducted with WLEDi lamps purchased in the Brazilian market. The sample used is representative of lamps with SSL technology, Edison base type (E-27). Six different brands were used (Black & Decker, Brilia, FLC, Galaxy, Kian, and OUROLUX), whose purchase price was considered accessible to the typical consumer in the Brazilian residential sector. The long-term experiment was conducted at IEE-USP, in a place with high ceilings (Electrical Machines Laboratory, building "I"). During the long-term test period, each lamp was mounted on support equipment that is provided with an electromechanical "hour meter" (non-volatile recorder), several lamp holders (the test rack), and electrically connected to a stabilized voltage source. The lamps were energized at a nominal value of 225 V, in the pendant position, with the base up, and under the ambient temperature. A separation of two lamp holders was adopted between lamps and aimed to minimize heat by mutually irradiating contiguous samples. Switching occurs during the sampling process when each lamp was removed from the test site and transferred to the measurement circuit and by the use of an integrator photometer, also when an eventual shutdown of the electric source occurred due to an unforeseen outage of the external network. No additional switching regime was imposed on lamps, E-27 (test body). After each specimen was removed from the rack, it was installed and energized inside the integrator photometer (period without energization: approx. 30-45 seconds), the light output reading was performed after a set period of five minutes. This was established after verification, concerning the value read after 20 minutes, and for the use of one reference lamp (# 9), when a difference or relative deviation of 1.6 % was verified. Records from three reference lamps were used, and data collection occurred at least ten times in the period considered from 1030 hours to 4473 hours of testing. The relative light output (concerning each reference lamp) was set at 100 % for the light output obtained at 1030 hours. This is due to the behavior observed in the period before 1030 hours, when more than one type of lamp had a maximum, value of light output. A curve (second degree) was used to adjust each set of points and, when necessary, it was obtained a mean of three values of the points at which the depreciation data curve intersects the 70 % light output line (or 30 % reduction concerning the light output obtained at 1030 hours).

The median useful life of the sample.

The median useful life of the sample was determined and is presented for three different conditions used here, namely: a) when half of the entire sample failed, catastrophically (it stopped emitting light);

b) when half of the entire sample has failed, in condition L_{70} (mixed, a catastrophic failure or no light emission); c) when it failed half of the entire sample plus one lamp (lamp # 7, 9 W went out), and not be considered the initial failure (# 8, 12 W, with 1407 h); remaining lamp brand # 3, # 5 and # 6. The mean was determined from the three determined median useful life values indicated above and the associated statistical parameters.

WLEDi lamp spectral emission and incandescent reference

Three lamps had their spectral emission (SPD) sampled using the Luzchem brand spectrometer, model SPR-03, series HR4C2217 (on loan from the IAG-USP). The input signal was collected by using a semi-sphere sensor with an internal PTFE coating coupled to the equipment by an optical fiber. To have a reference in the procedure, an incandescent lamp was used. This fourth sampling is important both to verify the response of the set and for future use if the same procedure needs to be repeated. The change in the emission spectrum is a characteristic of SSL technology, which changes throughout life, as reported in the literature.

Light transmission factor and SPD of the diffuser removed from WLEDi lamps

The bulb transmission factor was determined by measuring it with an integration photometer, using the lamp itself as a light source, and the reading of the light output of the complete lamp, after energizing, was taken when five minutes stabilization defined period had elapsed. The second reading was taken after removing the diffuser. The light output was sampled over a period longer than five minutes, previously, to measure the deviation due to the truncation procedure used. For the radiometric survey, a spectrophotometer was used at the Macromolecules Lab. of the Dept. PMT-EPUSP. The diffuser removed from the lamp body was installed next to the light output window of the spectrophotometer, whose survey was carried out by the equipment in a step of approximately 1 nm (operational condition of the equipment). Each diffuser was mounted and adjusted with the concave side (outer face of the diffuser) juxtaposed on the output window of the primary light source of a Varian brand spectrophotometer, model Cary 50 conc UV-Vis. Sampling was carried out for a diffuser removed from a WLEDi lamp and wavelength range (200 to 800) nm, with the "baseline" (equipment proprietary software) being adjusted for the condition without a sample from the sample compartment filled with only air of the environment. The condition of 100 % of the light transmission factor was fixed, arbitrarily, at 800 nm.

Label for the E-27 lamp (Lamp label) and road lighting luminaire in Brazil

The Brazilian consumer of WLEDi lamps, when examining the packaging, before making the purchase decision, will be able to see a type of label (INMETRO - PNE certification), whose edges are blue. This is called the National Energy Conservation Label - ENCE, in this case for LED lamps. Currently, there is a second type of "quality" label for street light sources. They contain information established, a priori, as a service by Product Certification Bodies - OCP (https://www.gov.br/inmetro/pt-br/acesso-a-informacao/perguntas-frequent/accreditation/certification-bodies-of-ocp-products) and INMETRO. Most labels are for lamp and luminaries' safety and performance certification. It can be understood as an element that allows the consumer to analyze product characteristics and make faster comparisons between different brands. This article considers the topic of labeling due to our understanding that it is an important instrument and can be improved with a central focus both on the consumer and on the final use of electricity.

Technical standard document (norm) analysis

A labeling program, in short, needs to be supported by a robust productive sector in the country, in proven local SSL metrological capacity, at least with open auditable procedures and technical standards. Thus, considering the assumptions raised true, the need to consider subjects on the technical standards was identified in this article. A brief report on the Brazilian sector is provided and a normative document and country are used to carry out an analysis considered pertinent. A suggestion for the Brazilian technical standard new projects is presented. The very important question formulated is about the necessity of limitation of the maximum temperature on the outside part of the WLEDi lamp body, E-27, this subject is considered and experimental data on the maximum temperature sampled by image procedure is presented.

The second experiment (with an expanded sample)

For the second intended long-term experiment, the sample is being expanded, both in brands and in the number of lamps. Some metrological activities were carried out for the second experiment and data are presented and discussed. In the second experiment, for the formation of the sample, two classes of products were considered, in theory, "brands considered worldwide" and local brands. In terms of nominal electrical power for stratification, 25 W was used (below and from this value). The initial part of the second experiment was conducted at 127 V, the lower-rated voltage value shown in the product catalog, and in the second part the characteristics of the sample when under 220 V were considered, usually the other rated electrical voltage value displayed on the lamp packaging, as well as the nominal life (L_{70}) of 25 thousand hours. The time settling for each lamp in the measurement procedure, before reading the instrument, was estimated to occur in a typical period of 55 minutes (for 0,5 % maximum variation, IESNA LM-79) which is considered to be too long. The so-called "burn-in" at lamp assembly locations with SSL technology has been considered the period that the WLEDi lamp remains energized after assembly has been completed. In the case of testing, "aging" is the period that the test body needs to operate under rated voltage before each measurement procedure can be performed. A brief literature review on key topics like this one is also presented and discussed.

The luminous efficiency of lamps from the Brazilian market

Luminous efficiency is a parameter present in the label of conformity that all WLEDi lamp needs to have to be at the points of sale. Processed data from measurements performed in the labs. of the IEE-USP are presented. The data for 35 test bodies was published in 2021 [4]. The averages (and standard error), for two energization voltage conditions (127 V and 220 V), maximum and minimum values, and range (max. - min.) of a sample containing 14 different brands, and range of (4.5 to 40) W. Similar parameter data from the European/Global market was accessed and considerations are presented.

THDi and Power Factor (PF and PF_1)

The expansion of the use of a light source other than incandescent, with a focus on increasing the efficiency in the use of electrical energy, motivated studies on the impact that the presence of sources with greater light efficiency can have mainly on parameters addressed in this part of this article. Initial characteristic measurements were sampled, at the power quality lab. of the IEE-USP, as relevant electrical parameters, including harmonics and PF with the ELSPEC brand equipment, model G4500 with five WLEDi lamps, 9 W, E-27, and PF > 0.70. For further analysis, given that they had already been sampled at another lab. (XITRON and YOKOGAWA, model WT3000), comprising a sample of 35 lamps. In the present opportunity, at the IEE-USP power quality lab., two tubular WLEDi, 9 W, base G-13, 60 cm, an incandescent lamp, and a CFL were included, intended to be used as a reference for metrological ballast and possible repetitions of the experiment conducted in different labs.

Light bulbs, electricity in the Brazilian residential sector

Data on the number of installed lamps and other data from the Brazilian domestic sector were also collected and presented.

Results

The first long term experiment (from Dec., 2018 to Nov., 2019, result)

The experiment with samples of WLEDi lamps purchased in the local market started on Dec. 17, 2018, and ended on Nov. 07, 2019 (total energization: 6991.4 hours). The instants of abrupt failures observed throughout the experiment were registered, which is related to failure (when the lamp permanently interrupted the emission of light). Luminous depreciation is other data obtained relating to failure due to a 30 % light output reduction. In the experiment, due to the different behaviors, the 100 % instant of the light output was considered at 1030 hours from the initial energization which occurred on Dec. 17, 2018.

Long-term experiment: the first 815 h (result).

For the first long-term experiment, lamps with the brands: Black & Decker, Brilia, FLC, Galaxy, Kian, Ourolux, and four different nominal powers were used: (7, 8, 9, and 12) W. The light output for each lamp was recorded throughout the experiment; luminous depreciation was determined and recorded. For the interval of the first 815 h the behavior was estimated using curve fitting, see Figure 2.

Figure 2. Results for the relative (ref. lamp # 9) light output of WLEDi lamps, base type E-27, during the first 815 h, at the first long-term experiment, sample with six different brands [9].

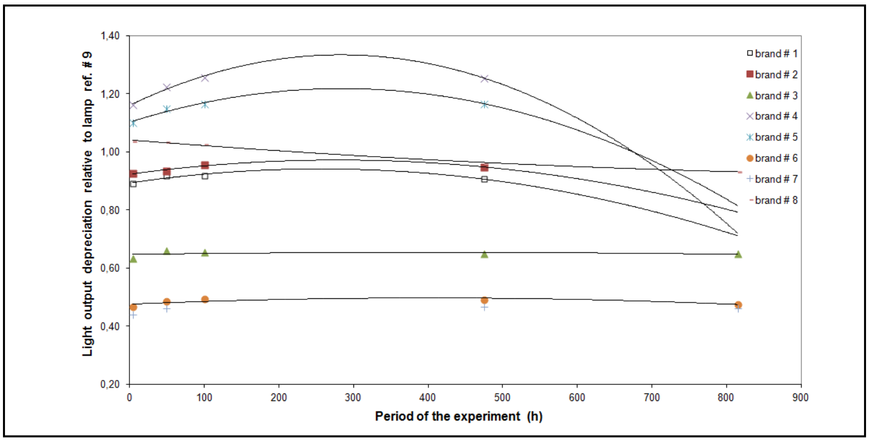


Figure 2 revealed four different behaviors for light output over the period considered. In the case of lamps # 3, # 6, and # 7, it was observed that the first result presented a slightly lower value than the other values that are considered, have reduced or little significant depreciation.

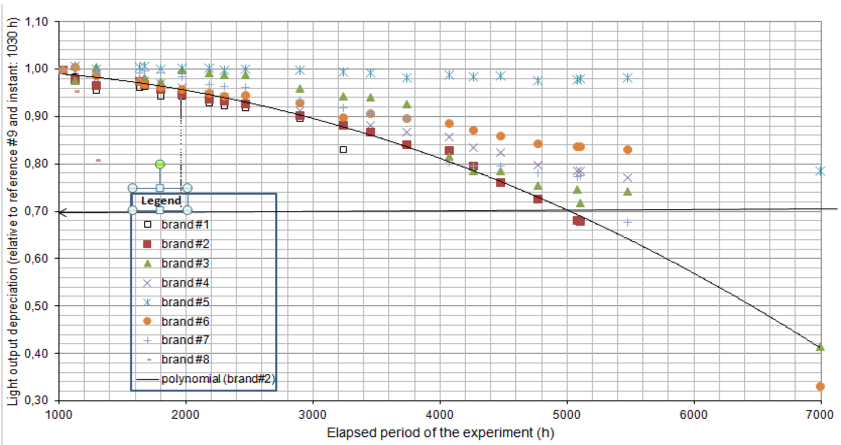
The depreciation results for the light output of lamps #1 and #2; #4 and #5 were adjusted by parabolic curves (second degree), and in the case of the last two lamps/brands, the depreciation rate was higher after the maximum region. Bulbs # 6 (7 W); # 7 (9 W), and # 8 (12 W) are from the same brand/distributor.

The question that arises: which instant should be used or considered as an initial? The publication LM 54 [10] advocates the need for seasoning for 100 h fluorescent lamps and the SSL technology (LED) there is no fixed period for seasoning "(LED). Season as recommended by the manufacturer".

Relative luminous depreciation (result).

The light output temporal variation (luminous depreciation) from each lamp brand was obtained, based on three references (lamps that were energized only when the procedure for measuring the specimens was carried out). After calculating relative luminous depreciation, to reference # 9 and the instant: 1030 h, the data were plotted along the elapsed period of the experiment (h) and are presented in Figure 3.

Figure 3. Relative luminous depreciation of sample lamps concerning the reference lamp (# 9) and defined reference instant 1030 h, from the first long-term test (Dec., 2018 to Nov., 2019).



In Figure 3 there is a horizontal line drawn for 30% depreciation (concerning 1030 h), that by definition is the L_{70} limit. The curve was also fitted (by Excel software), second degree polynomial only for lamp brand luminous depreciation data with mark # 2. The intersection point between the fitted curve and the horizontal line (L_{70}) defines the time of failure for the depreciation lamp brand identified.

The median useful life of the sample (result).

The median useful life of a sample containing six different brands of lamps was estimated for three situations considered and values as follows: a) (5521 ± 22) h, when half of the entire sample failed, catastrophically (it stopped emitting light).

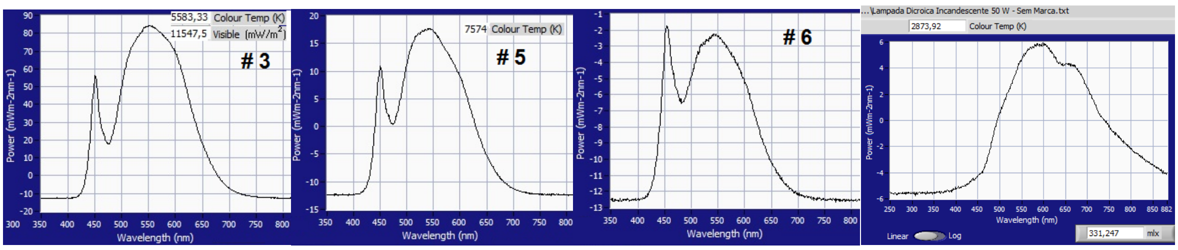
Note: The deviation was calculated as being half of the interval between two successive observations, whose second situation revealed that the failure occurred; b) 5400 h, when half of the entire sample failed, in condition L_{70} or mixed, with catastrophic failure (no light-emitting); c) 5930 h, when it failed (turned out at lamp # 7, 9 W) and the initial failure was not considered (# 8, 12 W, with 1407 h) the lamp with marks # 3 # 5 and # 6 (were emitting light).

The average median life of the sample was calculated as (5.62 ± 0.16) kh (it includes ± standard error), with a relative deviation value of 3 %, the calculation was performed using the three median life values as presented above. This represents only 22 % of the rated life as it is fixed on all WLEDi lamp packages purchased from the Brazilian market and used for the first long-term experiment (25 kh).

WLEDi lamp spectral emission and incandescent reference (result)

Three lamps had their spectral emission (SPD) sampled using a spectrometer. Even with the use of light input in a semi-sphere, the relative position between the light input from the sensor and the source can vary and, consequently, responses with different intensities and spectra can occur. To try to minimize this, an incandescent-type lamp with a dichroic reflector was used as a reference. The emission spectrum (SPD) of three brands of WLEDi lamps, base type E-27, # 3, # 5, and # 6 after 6992 hours of operation (long term experiment) and of an incandescent source are shown in Figure 4.

Figure 4. Results of SPD of WLEDi lamps, base type E-27, # 3, # 5, and # 6 (from left to right) after 6992 h, from the long-term experiment; on the right side, the incandescent source. Source: authors; Luzchem brand equipment with PTFE detector head as the light integrator.



The correlated color temperature (Tcp); the Spectral irradiance and illuminance are results from processing by the proprietary software of the spectral radiometer equipment, Luzchem brand, and model SPR-03 (HR4C2217 series) was used.

Light transmission factor and SPD of the diffuser removed from WLEDi lamps (result)

After removing the diffuser, the lamp was installed and energized inside the integrator photometer, it was not turned off and a second reading was taken. Thus, the variation can be considered negligible. The light transmission factor or light efficiency of the diffuser, considering reading values from the four minutes since the lamp was transferred from the test frame and the energization into the integrator photometer, resulted in an average (and standard error) of (82.7 ± 0.1) % for the lamp identified by # 13 and (82.4 ± 0.2) % for one with # 14. Approximately 17-18 % of the light produced by LED devices does not pass through the lamp's diffuser. The spectral transmission factor of four WLEDi lamps based on Edison type (E-27), two nominal powers, both without prior use (0 h), and a lamp that had a catastrophic failure (with 1407 h) was sampled in the spectral band (200 to 800) nm are shown in Figure 5.

Figure 5. Relative spectral transmission factor for the WLEDi lamp diffuser (9 W and 12 W; base type E-27), without use (0 h) and after 1407 h after the catastrophic failure occurred.

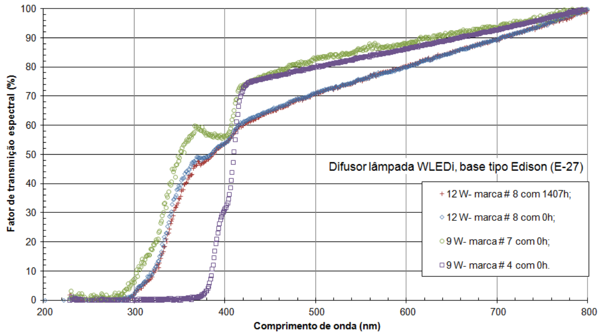


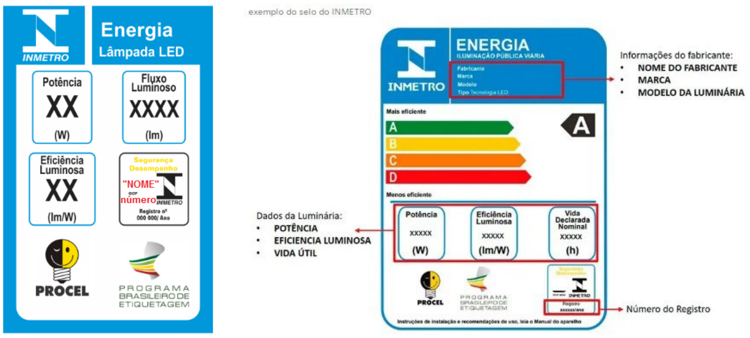
Figure 5 reveals possible depreciation, however, very few signs of the type (brand) # 8 lamp after 1407 h of use at the experiment and concerning another similar lamp, in the non-usage condition (zero hours). This result differs from the literature, acrylic diffuser (PMMA), which reveals appreciable attenuation above 400 nm and after 2000 h of testing [11]. The comparison between transmittance values at a given wavelength also suggests that they are quite different diffusers, with different materials in the composition (evaluated in this article and from the literature [11]).

In the city of São Paulo, ref. Dec., 2021, values (R$/kg) were obtained from a "walking scrap dealer" for metals: 0.8 Iron; 4 Aluminum; 40 Copper (clean). For plastics, similar information was not obtained due to the justification that it is necessary to identify and separate this type of material.

Label for the lamp (Lamp label) and road lighting luminaire in Brazil (result)

In the Brazilian market, LED lamps, since 2018, to be sold to the final consumer, need to have the INMETRO seal and respective certification, as established by INMETRO Ordinance nº 144-2015 [12]. Figure 6 shows, on the right, the seal (National Energy Conservation Label - ENCE) for LED lamps, and on the left, the seal for public street lighting, and the seals have different formats.

Figure 6. Brazilian label relating to safety and performance certification of LED lamps (on the left side) and for street lighting (on the right). Source: left, adapted from [13]; and the other from [14].



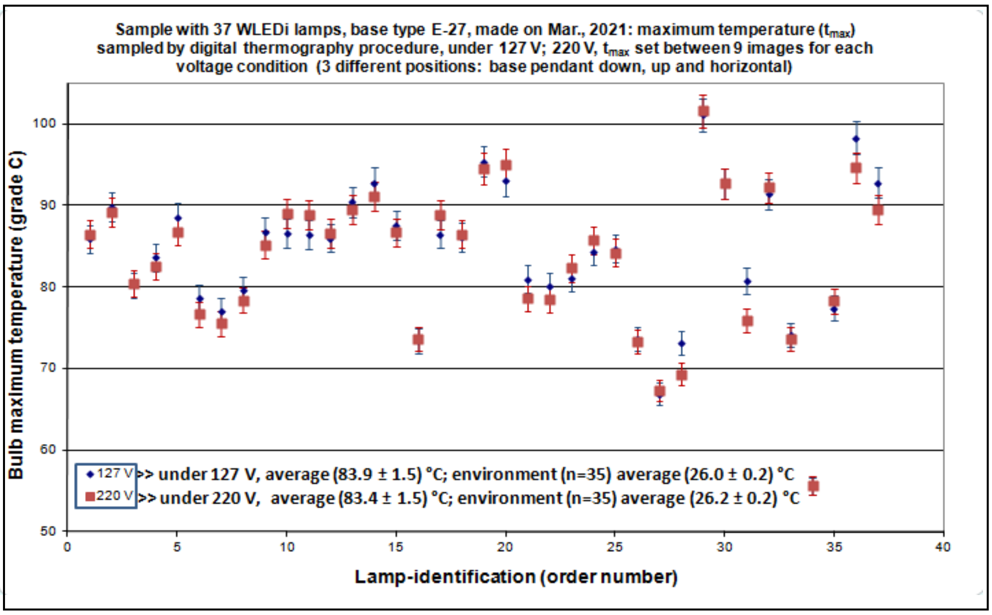
The example of a Brazilian label adopted for street lighting sources is similar to the first European label model. The research from the University of Coimbra points out that "the motivation of the Brazilian label system is based on two main factors: competitiveness and energy-saving and that the objective of the Brazilian Program for Energy Labeling (PBE) seeks to influence consumers to buy more appliances efficient ways to stimulate the competitiveness of the industry" [15]. Currently, the industrial sector of general-purpose electric light sources (base types E-27 and G-13) is no longer established in the country as a manufacturer, the assembler designation better reflects the practices that can be observed today. This article seeks to consider the topic of light sources label from the point of view of the consumer and the final use of energy.

Technical standard document analysis (result)

A technical standard is a basic instrument in any labeling program. It will enable the elaboration of procedures, which will allow technical documents such as reports from specimen characteristics. In Brazil, society's participation in national public consultation processes has evolved, going beyond the members of the Study Commission (CE), however, fluctuates a lot when considering the contributions registered in the ABNT system. For the international scenario and until the year 2015, considerations set by the Turkish academic sector were accessed [16]. The authors grouped the normative documents, mostly North American, into two groups, namely: a) Standards for the standardization of LED-type device measurement and recommendations, which brought together four documents, one of which is international, CIE and "LED Lamp and Luminaire Measurement Standards and Recommendations" which brought together four North American documents [16]. Only the CIE (2007) document is kept, all the other seven North American documents have an updated edition (IES LM-85-20, IES LM-80-20, IES TM-21-19; ANSI NEMA C78,377: 2017, IES LM-79-19, IES LM-84-20 and IES TM-28-20. Also, "The most important parameter that determines the performance of both the LED light source and the luminaries is the temperature" [16]. In Brazil, updates to the local normative document backed by an international standard (IEC) are taking place. The process is based on the Portuguese version of the IEC document chosen as of interest. For the ABNT COBEI Study Commission (SC), documents are made available that include a basic text.

In December, 2021, the (SC) started working as the basic text: project ABNT-CB-003 PROJECT 003:034.001-150 (IEC 62717; ABNT NBR IEC 62717) - LED modules for lighting in general - Performance requirements (53p.) [17], which is predicted to be identical to IEC 62717:2014 + AMD1:2015 + AMD2:2019" [18], the last edition of the considered IEC document. It is a normative document important and "new" in Brazil. The IEC PAS 62717, 2011, equivalent in Pakistan (PS: _5253-2017, ICS: 29.140.30), under the title LED MODULES FOR GENERAL LIGHTING- PERFORMANCE REQUIREMENTS was published in the year 2017 [19]. It was noted that the Pakistan standard was formulated based on IEC 62717, 2011 "LED Modules for General Lighting - Performance Requirements", it includes Amendment n.1 issued in September 2015 and incorporates modifications for the local conditions such as a modified electrical voltage range, from 80 % to 106 %; also the ambient air temperature modified to -10 °C to 50 °C; the inclusion of the provision of Surge Protection Device (SPD); and an Annex O designed to meet local requirements was verified for SSL technology: - power factor > 0.5; provision of overvoltage protection device (which compliance is recommended); 80 lm/W luminous efficiencies for bulb and tube LED lamp; 60 lm/W for panels and directional sources (lower hemisphere); and "up to 50 lm/W and above" for projectors and lights for road lighting. The first international version of the normative document, IEC PAS 62717, 2011, (Publicly Available Specifications; pre-standard) was a pre-standard that was canceled and replaced in Dec., 2014. The definitive version was published as IEC 62717:2014. That version introduced several changes to the "pre-standard (the year 2011)", two of which, due to their relevance, are presented and commented on below: - for electrical characteristics, the seasoning period can be chosen as 500 h; - for formatting photometric data files, reference is made to IEC 62722-1 (Sep., 2014). The IEC 62717:2014 received the second Amendment in January of the year 2019. In Pakistan, in addition to making changes considered relevant to the country, they use the text in the English language (without translating it into a local language version) and follow the IEC. Among the lessons learned during the activities within the technical standardization sector, one concerns the ease that an established normative document brings to the process. Document IEC 62471, 2006 already has a defined and numbered version for the Brazilian standard project (ABNT-CB-003 PROJECT 003:034.001-151 - Photobiological safety of lamps and lamp system, dated September 2020, but not yet defined as a priority. Another need noted is the absence of a procedure for calibrating a photometer. The IEC document indicates the lamp base as the location for determining the lamp temperature and "hopes it will not emit significant infrared radiation". In an experiment using a procedure with thermal image equipment, brand Flir, the maximum temperature was found to occur on the lamp body and not at the base. The lamp base is the common situation for the incandescent and HID lamps types, not for the WLEDi lamp. Figure 7 shows the maximum external temperature on the body of 35 WLEDi lamps, E-27 (the average value; for the environment under 26 °C), without significant previous use (~ 0 h), when energized at two nominal voltages of Brazilian networks (127V and 220V) and tree different position each lamp (including base up, down and at the horizontal plane).

Figure 7. Maximum external temperature at the body of 35 new WLEDi lamps (not used ~ 0 h).



The luminous efficiency of lamps purchased from the Brazilian market (result)

The mean, standard error, and range of values (maximum-minimum) of the sample with 35 lamps (base up) and 14 different brands were calculated, both when energized at 127 V and 220 V. Those statistics data from the sample are presented in Table 1.

Table 1. Statistics values for 35 lamps under 127 V and 220 V, 60 Hz.

Lamp WLEDi, E-27 (statistics)	**Luminous Efficiency (*) 127 V (lm/W)**	**Luminous Efficiency (*) 220 V (lm/W)**
average	105 ± 2	109 ± 2
maximum	138.1	139.3
minimum	82.7	84.4
Delta (max-min)	55.4	54.9

<u>Note:</u> (*) For the calculation of the average (± standard error) 35 results were considered under 127 V and 220 V.

The analysis of the values set in Table 1 concerning results collected from the literature [20] also for values of 127 V and 220 V, the authors used five different types of lamps, for three groups (C, D, and E [20]) there is an agreement between the results, the luminous efficiency presented a higher value for the 220 V condition. The article used above dates from the year 2015 [20], which allows us to infer that there was an increase, albeit modest, in the average luminous efficiency of this product class. The last two lamps included in the sample (for the next long-term experiment of the research) are based on type G-13 (WLEDi tube, length 60 cm) and have a nominal luminous efficiency of 100 lm/W.

THDi and Power Factor (PF; result)

The use of light sources with lower electricity consumption for an equal amount of light emitted increased the penetration of fluorescent technology. The impact of the presence of sources with greater luminous efficiency became the subject of research, which had the incandescent source as a guiding reference [21]. The abnormal voltage conditions of the electrical network also motivated different behaviors according to the type of circuit used to ballast the electrical current necessary for the technology of conventional tubular fluorescent lamps [22]. In the year 2005, the focus on the production of distortions (THD) and PF had shifted to CFL, also due to market penetration [23]. When evaluating the performance differences between a type of fluorescent technology (CFL) and LED, when under different power grid conditions, the Hispanic-Swedish group of researchers stated that the harmonic component emission depends on the driver circuit topology and THDv level of the real network, which differs from the low THDv conditions usually present in laboratory measurements [24]. Tables 2 to 4 present measurement results of active electrical power, total harmonic distortion (THDi) for the electrical current, total power factor (PF) of LED, E-27, lamps under 127 V, 60 Hz, calculations performed based on results from three different equipment, which include estimation for the displacement factor (PF_1, or the fundamental power factor component) [5].

Table 2. Active electrical power measured for lamps under 127 V, 60 Hz, and three different instruments, brand (YEW, XITRON, ELSPEC), values in W.

Lamp Identification: (number) code	**YEW (*) (W)**	**XITRON (**) (W)**	**ELSPEC (***) (W)**
(**#** 4) G3.1	8.475	--	8.32
(**#** 1) G3.5	8.671	--	8.50
(**#** 7) L1.1	7.700	--	7.61
(**#** 6) L1.2	7.454	--	7.32
(**#** 4) L2.1	9.037	--	8.90
incandescent	--	--	59.1 - 59.2
CFL	--	--	14.3 - 15.9
LED tubular (# 8)	--	--	8.9 - 9.0
LED tubular (# 9)	--	--	9.1 - 9.3

Notes: (*) YOKOGAWA (YEW) brand instrument, model WT3000, used until Mar.2021; (**) Values not available; (***) Measurements performed in a second lab. of the IEE-USP, in Nov., 2021, the ranges presented were estimated from the test sheets data; The ELSPEC incertitude estimation is 2.9 %.

The measurement of initial electric lamp characteristics, at the IEE-USP power quality lab., showed error for PF values previously obtained with the YEW brand equipment, WT3000 (all five specimens: # 4, # 1, # 7, # 6 and # 3 showed PF 0.99).

Still on the result of the PF with equipment brand ELSPEC, model G4500, XITRON and five WLEDi lamps, 9 W, E-27, PF > 0.70, comparatively, the XITRON equipment presented the lower value regardless of the type of WLEDi lamp considered.

Table 3. Total power factor (PF) for lamps, dimensionless values, and the total current harmonic distortion (THDi) for the electric current of lamps under 127 V, 60 Hz from three different devices, values in %.

Lamp identification (number/code)	**YEW (*) PF**	**XITRON PF**	**ELSPEC PF(**)**	**YEW (*) THDi (%)**	**XITRON THDi (%)**	**ELSPEC THDi (**) (%)**
(**#** 4) G3.1	0.956	0.952	-0.956	28.7	28.9	27.8
(**#** 1) G3.5	0.958	0.949	-0.957	25.9_5	26.6	24.9
(**#** 7) L1.1	0.935	0.930	-0.935	36.2	35.9	35.2
(**#** 6) L1.2	0.935	0.924	-0.934	34.9	34.6	33.6
(**#** 4) L2.1	0.975	0.968	-0.972	17.9	18.2	16.77
incandescent	--	--	-0.999_5 to -1.000	--	--	0.234 to 0.332
CFL	--	--	-0.594 to -0.607	--	--	100.0
LED tubular (# 8)	--	--	-0.978 to -0.984	--	--	14.81 to 16.52
LED tubular (# 9)	--	--	-0.986 to -0.988	--	--	7.61 to 9.45

Notes: (*) YOKOGAWA (YEW) brand, model WT3000, used until Mar., 2021, the PF values shown are the result of a calculation performed (the data presented for the equipment were changed after the fourth acquisition of the 35 lamp set), for further information, see text above, at the beginning of this part of the article, "THD, Power Factor (PF; result)";
(**) Measurements were performed at a second lab. of the IEE-USP, in Nov., 2021, the values that have a negative signal can be viewed as capacitive load. The ranges presented were estimated from test sheets data, and the nominal incertitude is ± 0.2 % (true power factor) and ± 0.25 % (THDi).

Table 4. Average for values of three different types of equipment of the total power factor (PF), total harmonic distortion (THDi), electric current, and PF_1 of the fundamental component of lamps under 127 V, 60 Hz.

Lamp identification (number/code)	**PF (*) (%)**	**THDi (%)**	**ELSPEC Electric current (**) fundamental component (A)**	**PF_1 (***) (%)**
(**#** 4) G3.1	95.4 ± 0.1	28.4 ± 0.3	0.066	99.2
(**#** 1) G3.1	95.5 ± 0.3	25.8 ± 0.5	0.068_5	98.6
(**#** 7) G3.1s	93.3 ± 0.2	35.8 ± 0.3	0.060	99.1
(**#** 6) G3.1	93.1 ± 0.4	34.4 ± 0.4	0.059	98.4_5
(**#** 4) G3.1	97.1 ± 0.2	17.6 ± 0.4	*0.070_5*	98.6
incandescent	--	--	*0.47*	--
CFL	--	--	*0.132_5*	--
LED tubular (# 8)	--	--	0.071	--
LED tubular (# 8)	--	--	0.073	--

Notes: (*) For the calculation of the mean (± standard error) each value calculated for the YOKOGAWA equipment and converted into % was considered, and for the calculation of the standard error in the mean, n= 3 was used;

(**) Estimated result of test sheets carried out in Nov., 2021 that graphically present the relevant harmonic components; and

(***) Estimated result based on approximate calculation, as per ref. IEEE Standard 1459-2010, item 3.1.2.16 Power factor, p.12-13 [25].

The ELSPEC equipment, in the sampling of the five WLEDi lamps, 9 W, always presented the lowest THDi value among the three types of equipment used (XITRON and YOKOGAWA). Those five lamps that had been measured in another laboratory (with equipment brand: XITRON and YOKOGAWA) within the sample of 35 lamps (sampled in Nov., 2021), it was measured again together with two tubular WLEDi, 9 W, base G-13, 60 cm; one incandescent lamp and one CFL intended to be used as a reference in possible repetitions of the experiment conducted in the IEE power quality lab.

Light bulbs, electricity in the Brazilian residential sector

Having the capacity to estimate the number of light bulbs installed in a Brazilian home sector is important for the planning end-use of energy, estimating the sectorial consumption of electricity. MARCOS PEREIRA ESTELLITA LINS, et al. 2002 [26] presented an estimate for the year 2002 in this regard, based on a survey carried out for the National Electric Energy Conservation Program - PROCEL by Brazilian electric energy concessionaires (still state-owned). The consumption estimate is presented in Table 5 and it was based on the nominal electrical power (60 W) of the incandescent lamp.

Table 5. Modeling results for the residential sector from PROCEL survey (year 2002) data [26].

Country region and Lamps Number (amount)	**Lamps/ Residence**	**Consumption monthly (kWh/month)**
BR 76,315	8.115	4.008
North 32,186	7.046	5.116
South 44,136	9.125	2.664

VILLAREAL, M.J.C. et al. 2016 [27] described the consumption of electricity in Brazilian households between 1985 and 2013, using linear regression and as "explanatory variables" they used the number of households, the actual consumption of families as a source of family income and the electricity tariff for the households. Thus, they were able to account for the reduction in household electricity consumption caused by the energy crisis in 2001. They safely suggested the existence of a long-term relationship between household electricity consumption and the explanatory variables. For the year 2012 and Brazilian consumption of electricity for light bulbs in the residential sector, they presented the 15 % fraction (or about 17 TWh), after electric showers (first) and refrigerators (second). Another study made by ABRAHÃO, KC de FJ; SOUZA, RVG de., 2021 [28] analyzed the residential consumption of electricity in Brazil, between 2000 and 2018, and presented as main results: "(i) the growth of the number of households was recognized as one of the main drivers of consumption growth; (ii) household income showed no control over consumption in hot climate regions, except in low-income households; (iii) the tariff showed to impose restrictions on consumption, mainly in low-income households. In an unprecedented way, the results showed that residential electricity consumption in Brazil varies with the age of the population, with a tendency for consumption to grow up to 59 years of age, and a sharp reduction from this onwards 60 years old".

Discussion

For the year 2012, the Brazilian consumption of electricity in the residential sector, for light bulbs, received an estimation of 15 % of the total, around 17 TWh [27]. Data collected (twenty years ago) showed estimation of 8.1 lamp/house, monthly electricity consumption of 4.0 kWh/month, and considered as the most frequently occurring lighting load bulbs (Brazil, 2002), 60 W incandescent [26]. The second published data (Brazil, 2019) indicates an average, reduced, value of 6.50 lamp/house [2].

This article considered aspects related to lighting in the Brazilian residential sector and the SSL light bulb technology (Inorganic White Lighting Emitting Diode - WLEDi) marketed in developing countries, such as the initial electrical, photometric characteristics, radiometric characteristics (7 kh), light depreciation, median sample useful life, includes aspects to broaden the discussion on the final use of electrical energy, light output efficiency, power factor, THDi, technical standard, labeling, the implications of plastic waste at the end of the product's useful life, the part of the lamp considered was the light diffuser and prices (scrap dealer) to value discarded metals, a topic that sought to lay the foundation for future investigation of possible actions whose benefits will not be energetic. Lamp failure and light output depreciation data were collected during a long-term experiment with WLEDi lamps purchased in the Brazilian market.

The result of the long-term experiment showed agreement with the users' position; the brands used in the sample are not global (from the four traditional lamp manufacturers). The occurrence of reports from local consumers about the product's very short useful life has been verified. This agrees with a statement by NARENDRAN, N., 2017 [29] made based on a study focused on the reliability of the LED system, he revealed that: "some LED products available in the US consumer market and certain applications, they can fail much earlier than the manufacturers' specifications suggest to consumers." And that "industry test standards will evolve to ensure more accurate LED system life estimates" [29]. Data that could support a useful life of 25 kh (L_{70}, at the packaging of all lamps) have not yet been collected locally. Luminous depreciation was quantified and is presented together with other results. Luminous depreciation has distinct behavior groups; it is not similar, even for a single brand. The catastrophic failures (when considering SSL technology) occurred in the inverse order of the nominal electrical power, first to 12 W, then 9 W. Lamps that did not show abrupt failure after 7 kh of the experiment are 8 W and 7 W. Only brand # 5 (coding used for results dissemination purposes), nominal 8 W did not show L_{70} fault until 7 kh of the first long-term experiment conducted.

There is still no closed definition concerning the lamp seasoning period, that is, which time should be considered as an "initial" or "zero hour" condition. For 5 mm LED type, there is information in the literature about: The lifetime" of the LED device (5 mm encapsulation) for the signaling sector has been set at 50 % of the light output not from the initial one, but for the light output of LED devices it was verified to occur at 192 hours after the initial energization (industry's standard definition for lifetime [30]). Currently, the "useful life" information contained in the packaging of lighting products has a different useful life time definition[275], which can be interpreted by the consumer as elapsed 25 thousand hours of the product use it should still be able to provide light depreciated by up to 30 % concerning the "initial light output". Therefore, for LED (5 mm) the suggested minimum seasoning period used to be 192 h.

The current IEC 62717 document [18] has three references to the term aging time: a) recommends (can be chosen) 500 h for electrical characteristics; b) p.13, Table 1, item k, Mandatory appointment if the seasonal period is different from zero hours; and c) p.27, Method of LED measuring module characteristics, "Unless otherwise declared, LED modules do not require any aging before testing. An aging period of up to 1000 h may be specified by the manufacturer [18]. As shown in this article (see Figure 2 and related text) the light output behavior at the first 815 h varies according to the type of WLEDi lamp; - p.25 [18], unless otherwise specified, all measurements shall be made in a draft-free room at a relative humidity of 65 % maximum."

[275] (L_{70}) or useful lamp life that is equivalent to the time the LED light source takes until its light output (luminous flux) reaches 70 % concerning the initial luminous flux.

Therefore, there is a limit for the maximum relative humidity, suggesting that the high relative humidity influences the measurement to determine the characteristics of the so-called "LED module".

It does not have scale, capable of identifying differences between products and facilitating understanding for the consumer, in addition to the luminous efficiency value. The suggestion of this article is to incorporate other parameters, within a scale to be built that can increase the useful information to the consumer when making a purchase decision, in addition to the price of the product. When doing a local search on the status of the number of records of the WLEDi lamp product in the Brazilian market with a label, records could be accessed from an internet tool that can be used (the electronic address to assess it is: http://registro.inmetro.gov.br/consulta/). The label (PBE) contained in the WLEDi lamps sold in the Brazilian market differs from the European model.

The measurement of initial characteristics, in the power quality laboratory of the IEE-USP, of the electrical parameters revealed the occurrence of an error in the previous sampling, for PF values with the equipment brand YOKOGAWA - YEW, WT3000 (all five specimens: # 4, # 1, # 7, # 6 and # 3 had presented PF 0.99). The change occurred during the sampling of 35 lamps, the first readings of the PF with the YEW equipment, the three reference lamps, and the first lamps were correct only. The verification was carried out from active and apparent power, however, an unexpected change occurred and resulted in non-conforming values.

Based on the records obtained with the equipment ELSPEC brand, model G4500, five WLEDi lamps, 9 W (nominal power), and considering a suggestion from the literature [25] for approximation on calculation procedure, the fundamental component displacement factor (PF_1) for the five lamps was estimated (see Table 4). Although approximate, the calculation result enables analysis concerning an older technology, the CFL displacement factor (p.225, Table 13 - Power factor and displacement factor values) from the literature [31]. The authors presented a scenario regarding the replacement of 90 % of incandescent lamps by CFL, which led to a degradation of the parameter PF and (PF_1), both from 0.95 to 0.84 (PF) and 0.86 (PF_1) from measurements carried out at the output of the distribution transformer. In the case of the WLEDi lamp from the Brazilian market {(# 4) G3.1}, PF, an average (from three instruments reading) of (95.4 ± 0.1) % was defined, and for (PF_1) a calculated value of 99.2%, both higher regarding load configuration with the CFL analyzed from the literature [31]. The access and evaluation of values of luminous efficiency between light sources have been a widespread practice used to point out the technology limit of a certain family of type A WLEDi lamps (base E-27) concerning results obtained from experimental practices. The data for luminous efficiency that was obtained from the IEE-USP laboratory by sampling 35 lamps specimens provided were processed and the representative statistics were fixed and presented in Table 1. The average value was analyzed concerning data from specimens evaluated in Brazil, also at two energizing voltages representative of the electrical systems [20], having revealed evolution on a time basis. There was an increase, albeit timid, in the average luminous efficiency between the sample's average values, in an absolute of 4 lm/W (3.8%).

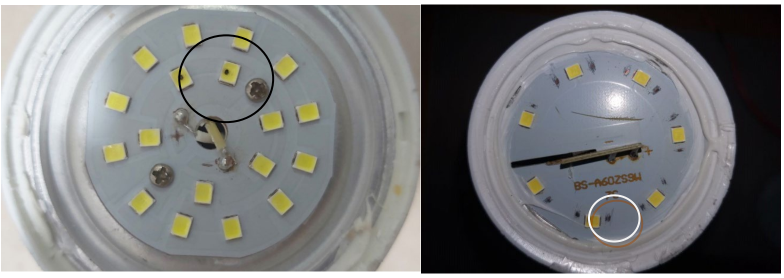
Improvement can also be observed concerning the values presented in Table 3 and data from the literature for the year 2015 [20], the same specimens, and considering the THDi parameter. In the current sample, although reduced, the presence of a specimen with high THDi (> 86 %) was not observed.

There are seven lamps from the sample (35 lamps) with a maximum temperature above 90 °C and one above 100 °C (see Figure 7 – Maximum external temperature at the body of WLEDi lamps) Do they have a Brazilian safety compliance label (the answer is yes, they do).

To increase the robustness of the analysis of the luminous efficiency values determined in this article, they were compared to the data set out in the literature [32]. A reference value is a reference to the Chinese standard (GB 30255-2019 - Minimum allowable values of energy efficiency and energy efficiency grade of LED products for indoor lighting) at a point of the order of ≥ 62 lm/W regardless of the light output values between zero and 2.5 klm; the European standard (the year 2019) whose reference line limit increases with a logarithmic and continuous profile, concerning the increase in light output (at x-axis) and it crosses the threshold of 100 lm/W (horizontal line parallel to the x-axis) close to 1.5 klm [32] The records of specimens indicate a maximum of 160 lm/W (close to 0.55 klm) and the highest frequency of records is between (80 and 120) lm/W. For the light output corresponding to the incandescent pattern, 60 W registers are in the range from the Chinese standard limit to close to 135 lm/W. Furthermore, the part of item 4.4 "Lumen maintenance", from the Chinese standard (GB 30255-2019) states that for LED lamps at 3000 h the light output must not be less than the required nominal lumen maintenance associated with the expected rated life at that period. According to the stated nominal life, the required lumen maintenance value must be classified according to a formula that could not be accessed in the literature yet.

After more than 20 years that NARENDRAN, N., et al. 2001 [33] posed initially a relevant question for discussion by the scientific community: “What is useful life for white light LEDs?”, accompanied by the argument that "the LED device, normally, does not present catastrophic failure, it presents continued depreciation", the results presented in this article demonstrate that catastrophic failures exist, and its manifestation can be visible to the naked eye, as shown by the marks on the top of the devices shown in Figure 8 for the closing of this article.

Figure 8. WLEDi lamp (E-27), 9 W, type with ID #1, after 3255 h (catastrophic failure, at right); another module with two defective devices on the left (see device inside the circle).



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Advancing Plug Load Efficiency with Utility Incentive Programs

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Abstract

Energy efficiency (EE) programs largely focus on incentivizing investments in major end uses, particularly in heating, cooling, and lighting. However, to meet aggressive goals for reducing GHG emissions researchers and policymakers must also address energy inefficiencies of plug load devices, most of which individually use relatively little energy but are present in ever-growing numbers. In the U.S. commercial sector, end uses such as cooking, computing, and office equipment made up 18% of the electricity purchased in 2019 while "other" uses, such as medical and laboratory equipment, made up 32%. Energy use from plug load devices is expected to rise due to increases in both the types and numbers of devices. Incentivizing customer investments into more efficient models and efficient use of these devices is complicated by several factors, including the wide range of device types and usage patterns. This paper presents research on how U.S. utilities can highlight plug loads in their commercial EE programs. We report results of an in-depth examination of the EE programs of 20 major U.S. utilities, reviewing the types of downstream and midstream incentives and other approaches they use, and linking them to best practices. We offer recommendations about how to effectively integrate plug loads into utility EE incentive programs and discuss barriers.

Introduction

Energy efficiency (EE) programs are motivated by growing concerns about the increasingly serious effects of climate change, grid instability, and lack of energy security [1]. The goal of these programs is to promote cost-effective solutions that reduce and manage energy consumption. Most EE programs in the U.S. focus on HVAC, lighting, and refrigeration; as these become more efficient, plug load devices are an emerging area for savings. Plug load devices are appliances and equipment that plug into standard electrical sockets. In commercial settings this includes such devices as computers and printers in offices, projectors in conference rooms, cash registers in retail outlets, televisions and food service equipment in restaurants, and refrigerators and water coolers in staff breakrooms. Total energy use attributed to plug load devices has risen as the number of such devices in commercial buildings has increased, and there is consensus that plug load energy consumption will continue to grow [2-4]. There is evidence that organizations that implement both technological and behavioral strategies observe a significant decrease in plug load energy consumption and waste [5-9]. Utilities can support their commercial customers in reducing their plug load by offering EE programs that are tailored towards this goal.

In this paper, we present the first large-scale survey of how U.S. utilities are incentivizing EE plug loads in their commercial programs. The goal is to describe the range of approaches attempted by various utilities across the country and identify which have already been more widely adopted, and for which plug loads, and which are less common. In either case, these approaches represent potential energy-saving opportunities for utilities that have not yet fully integrated plug loads into their portfolios. We begin with a brief review of prior research. We then describe the policy context for U.S. utility programs, and how downstream, midstream, and upstream incentive strategies are divided across government and private entities. We then report results of research on commercial EE programs in twenty major utilities across the United States. Our conclusions highlight the various program strategies identified to reach the goal of reducing energy consumption and thus greenhouse gas (GHG) emissions from plug loads.

Prior Research

There have been relatively few comparison studies of utility energy efficiency programs in the United States. Each utility is required by individual states to collect and analyze cost effectiveness data for their program offerings. However, these requirements vary in terms of the quantity and quality of public-facing reports describing program success in reducing energy usage and customer bills. The most widely cited program comparison analyses are conducted by the American Council for an Energy Efficient Economy (ACEEE), producing annual scorecards ranking the top performing utilities on a variety of metrics, such as range of program offerings, program portfolio comprehensive, and selected spotlights on emerging program areas, such as electric vehicle supply equipment, and programs directed at helping disadvantaged customers and communities [10, 11]. ACEEE also publishes reports ranking top states and cities for energy policies, which supports their research on utility performance. In addition to ACEEE's work in this area, there is also an established body of research analyzing the relative economic rewards and trade-offs of particular device incentives and program design and delivery [12-14]. Our research is unique in focusing exclusively on plug load devices, which do not receive much attention in the literature, especially when compared to other building loads such as HVAC and lighting. Furthermore, our descriptive approach serves as a "best practices" model to demonstrate implementation methods and examples for different types of programs and geographical areas, as a complement to other research that focuses on levelized economic impact analysis across utilities and program types.

US Policy Background

It is useful to briefly describe the policymaking context for plug load-related codes and standards in the US. Federal law requires minimum efficiency standards for most domestic and commercial "white goods" appliances. These minimum codes are supported and advanced by additional voluntary labeling programs such as ENERGY STAR, which requires higher levels of efficiency performance and provides qualified product lists to help customers make informed decisions. State laws may build upon minimum federal standards for their jurisdictions. For example, California Title 20 both increases minimum efficiency requirements for federally regulated devices and extends plug-load standards to a greater variety of end-use products, such as consumer electronics (e.g., televisions and desktop computers) [15, 16].

Individual states also have the authority to set requirements for utilities in their jurisdictions for providing energy efficiency incentives. The major utilities in turn are fully responsible as independent operators to incorporate state mandates into their program portfolios, e.g., through offering rebates on EE equipment. This produces an uneven application of programs at the national level, with some states (e.g., California) vastly outperforming other states in the robustness of EE program portfolios.

The primary goal of state and local governments and utility providers is to encourage residents and businesses to use less energy and adopt energy-saving products and practices. There are multiple delivery mechanisms for implementing EE incentive programs: upstream, midstream, and downstream. Upstream programs are aimed at changing manufacturing practices, e.g., through the inclusion of efficient and eco-friendly parts. These changes can be spurred by regulations enacted by federal and state governments as well as codes developed by professional organizations such as ASHRAE and IEEE in the U.S. Utilities operate solely at the downstream and midstream levels. Downstream programs are aimed directly at end use customers, typically through rebates of qualified energy-efficient HVAC, lighting, and other equipment. By contrast, the goal of midstream programs is to increase the market share of energy-efficient products by incentivizing distributors and retailers to stock these products and make them readily available to customers, rather than incentivizing customers directly [17].

Importance of Plug Load Devices for EE

Miscellaneous electric loads (MELs) are all building electrical loads that are not associated with HVAC or lighting, the traditional end uses targeted by utility EE programs [3, 18-20]. The majority of MELs are not regulated by federal standards [1, 4], which creates an opportunity for EE programs to steer the market towards more energy-efficient solutions [21]. MELS include both plug loads (freestanding devices that plug into outlets) and process loads, which are hard-wired into the building circuitry and include systems such as security cameras and doorbells. Process loads are often sold, installed, and incentivized differently than plug loads, and are outside the scope of the current project.

MELs are getting more attention as the traditional end uses, such as HVAC and lighting, have become more energy efficient in commercial buildings [22]. Thus, the relative contribution of MELs to a buildings' total energy consumption is increasing [1, 23]. Moreover, the amount of building energy use attributed to plug load devices has also been on the rise as the absolute number of such devices in commercial buildings has been increasing, and there is consensus that the energy consumption from plug loads will continue to grow [2-4].

Approach and Methodology

This report is an extension of a study performed by the California Plug Load Research Center (CalPlug) for Commonwealth Edison of Illinois, assessing how they might expand their EE program opportunities for greater inclusion of plug load devices. That study focused on a deep dive into one utility's EE programs, comparing them to those of other utilities, to make specific recommendations. The current study pulls back to assess all the target utilities' programs for a broader view on opportunities across the portfolio landscape.

As described earlier, the goal of this study is to review potential downstream and midstream incentive approaches for utilities to target plug loads in their program portfolios. We took a three-pronged approach to identify potential opportunities for plug load related program recommendations. First, we compiled a list of plug load devices and selected devices that were the most promising for achieving energy savings and positive program return on investment potential. Second, we identified all the energy efficiency programs that involved plug load devices in the portfolios of a list of 20 U.S. utilities, based on top performers in the ACEEE Utility Scorecard rankings [11]. Third, we compared these programs to best practices. The results are descriptive; evaluating the effectiveness of all of these programs across or between utilities is beyond the scope of the current project, as is assessing whether any given approach would be cost-effective for a specific utility. To better illustrate how strategy adoption might take place for utilities that do not currently fully incentivize plug loads, we sorted the potential opportunities into three groups: adding a plug load-related program; adding specific plug load devices to existing programs; or modifying the approach of current programs.

Device Selection

The first step was to identify commercial plug load devices that should be considered. We compiled an initial list using inventory and monitoring studies conducted in a range of office buildings and other institutions [1, 22, 24, 25] and from the product list of the Office of Energy Efficiency & Renewable Energy [26]. The next step required determining whether each device offered an energy efficient alternative that could be incentivized, either through utility rebate programs, or point-of-sale discounts. For the majority of devices, this meant locating data on average energy consumption for ENERGY STAR-certified models versus non-efficient models of the same type of device. Some devices did not have ENERGY STAR (or other certification) options but did offer an alternate type that saved energy due to a technological improvement. For example, heat pump dryers are currently assessed under the broader category of clothes dryers, and do not have separate qualification requirements.

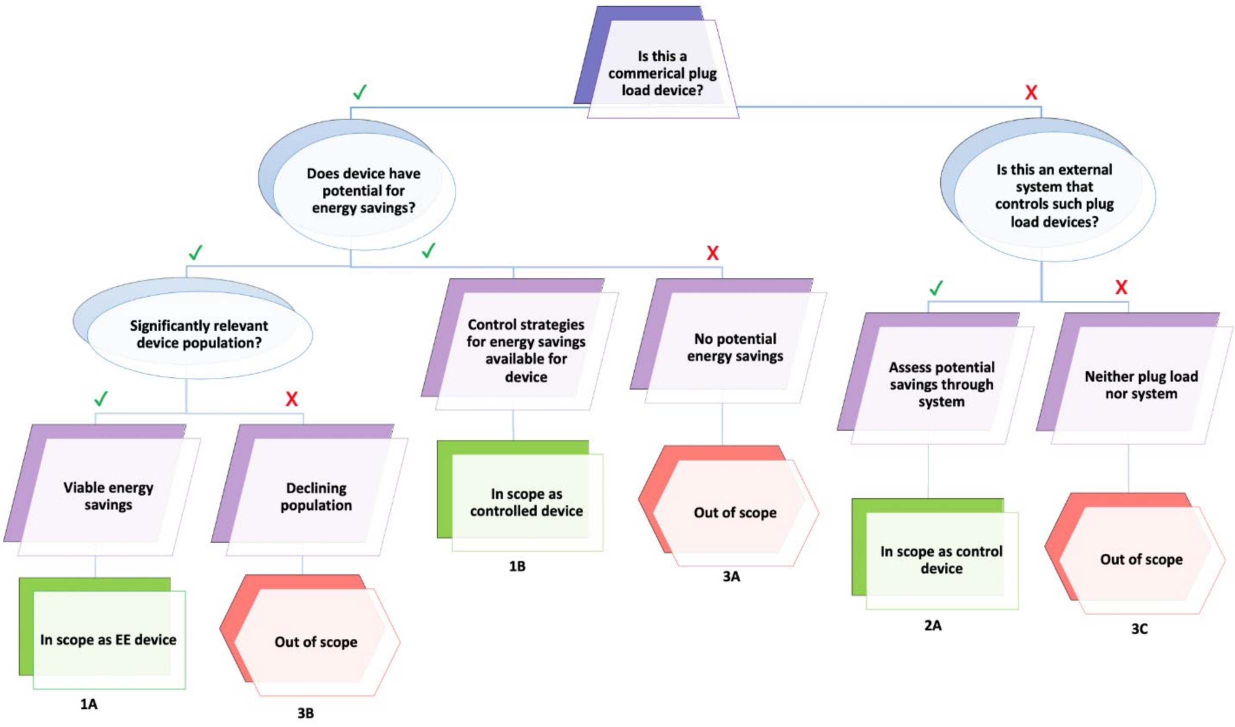
Primary data sources included: Federal Energy Management Program (Energy.gov); Stanford Study [27]; Office Plug Load Field Monitoring Report [28]; and ENERGY STAR. After exhausting the top four sources, additional individual sources were found for the remaining devices, most providing data for only one device each.

The estimates for energy usage and energy savings derive from many disparate sources and thus reflect a range of unspecified assumptions and selection criteria. Given this limitation, we are cautious about quoting energy savings for devices, which implies the ability to compare savings across devices. We cannot justify using this information to make more detailed calculations about cost-effectiveness. Instead, the estimates are accepted as *prima facie* evidence that a potential for energy savings exists, and no minimum bar is set for potential consideration.

The team determined whether each device was in scope for the current assessment by using a decision tree, shown as a flowchart in Figure 1. Specifically, a device was considered in scope if it:

1. Offers the potential to save energy through an available energy-efficient alternative, usually an ENERGY STAR-certified option, but possibly another energy-efficient technology; OR
2. Can be made more energy efficient by using plug load control strategies; AND
3. Shows sufficient device population; OR
4. Is a system that controls plug load devices

Figure 60. Device Selection Flowchart



Selection was biased toward inclusion rather than exclusion. For instance, any device with an energy saving alternative met that criterion, regardless of the extent of the savings potential. Only two devices were determined to have low enough future population in the commercial sector to justify excluding: DVD players and VCR players.

The device flowchart narrows down selection by removing devices that do not have energy savings alternatives and are declining in the current market. In addition, the flowchart helps to identify which plug load devices can be effectively controlled by external systems, usually through simple power cuts. Such systems can be implemented with existing or new devices, for example a Tier 2 Advanced Power Strip (APS) paired with computers and computer peripherals such as speakers and printers. Table 1 contains a detailed list of the devices determined to be in scope, along with their selection criteria.

Table 28. Selected Plug Load Devices and Standard Incentives in Commercial EE Programs

Devices in Scope	**Device Code**	**Devices in Scope**	**Device Code**
Computer, Desktop	1A, 1B	Cash Register	1A
Computer Monitor	1A, 1B	Residential Freezer	1A
Computer, Laptop	1A, 1B	Residential Refrigerator	1A
Thin/zero client	1A, 1B	Mini-Refrigerator	1A
Computer Power Management Software	(INAP)	Commercial Freezer **	1A
Printer/Copier	1A, 1B	Commercial Refrigerator**	1A
Scanner	1B	Residential Dishwasher	1A
Multi-function Device	1B	Commercial Dishwasher**	1A
Plotter	1B	Commercial Oven **	1A
Server	1A	Fryer **	1A
UPS Units	1A	Hot Food Holding Cabinet	1A

Television	1A, 1B	Griddle	1A
Projector	1B	Wrap Machine	1A
Audio System	1B	Steam Cooker	1A
Speakers	1B	Refrigerated vending machine	1A
Advanced Power Strip, Tier 1	2A	Vending Machine Control/Miser	2A
Advanced Power Strip, Tier 2	2A	Ice Machine	1A
Smart Plug	2A	Microwave	1B
Plug Load Occupancy Sensor	2A	Coffee Maker	1B
Paper Shredder	1B	Espresso Machine	1B
Task/Desk/Floor Lamp	1B	Toaster/Toaster Oven	1B
Room AC	1A, 1B	Hot Water Dispenser	1B
Dehumidifier	1A, 1B	Water Cooler	1A, 1B
Space Heater	1B	Clothes Dryer	1A
Fan	1B	Commercial Clothes Washer	1A
Pool pump (VSD)	1A	Residential Clothes Washer	1A

Utility Selection

Selection of utilities to examine was based in part on whether their plug load programs or overall portfolio had earned accolades in the 2020 American Council for an Energy-Efficient Economy (ACEEE) utility scorecard, which many researchers in the field consider to be a "gold standard" resource for utility program analysis and rankings [11], or had other indications of strong performance on EE programs in general. As the initial research project was funded by Commonwealth Edison (ComEd) in Illinois, utilities in nearby or similar geographical and climate regions were also prioritized.[276] We also consulted the Better Buildings Plug Load Efficiency Utility Incentives List, published by the U.S. Department of Energy, which lists all plug load products included in U.S. utility incentive programs, and compares incentive amount data across utilities.

Utility EE Program Comparisons

The research team compared all EE programs and program components across the 20 selected utilities to assess their inclusion of plug load devices in individual incentive and holistic programs. These programs were either device-targeted (such as specific, or standard, incentive amounts for particular qualified products), or were directed at the level of a holistic program (such as programs targeting small businesses, online marketplaces and midstream delivery systems, and customizable whole-building projects). Thus, two main approaches emerged: device/controls incentives and integrated, holistic programmatic strategies. The key quantitative results of these comparisons identify the types of programs that incorporate plug load devices and how many of the examined utilities use that strategy. The key qualitative results look in more detail at how exactly the programs incorporate plug load devices and applies advice from best practices to these strategies.

After selecting the 20 comparison utilities, we consulted the websites of each company for greater detail of their specific programs. Information obtained included not only incentive amounts for specific devices, but

[276] Specifically, utilities included: Ameren Illinois (Illinois); Baltimore Gas and Electric (Maryland); Commonwealth Edison (Illinois); Consolidated Edison (New York); Consumers Energy (Michigan); Efficiency Vermont (Vermont); Energy Trust of Oregon (Oregon); Eversource Connecticut (Energize CT) (Connecticut); Eversource Massachusetts (Massachusetts); Florida Power and Light (Florida); Georgia Power (Georgia); National Grid (Massachusetts); New York State Electric and Gas (New York); Pacific Gas and Electric (California); Sacramento Municipal Utility District (California); San Diego Gas and Electric (California); Southern California Edison (California); We Energies (Focus on Energy) (Wisconsin); and Xcel Energy (Minnesota)

also information on program design, program customer targets/industry segments, and detailed fact sheets on installation steps and how to obtain rebates and/or instant discounts. We entered these details into a comprehensive spreadsheet to facilitate the analysis of quantitative data (i.e., incentive amounts, number of participating utilities), and qualitative data (how programs were implemented and marketed to customers). We also evaluated the user experience of each utility's website interface, such as ease of access and logical links between pages, clarity of language and presentation of program outlines and requirements, inclusion of useful diagrams/images, and general aesthetic quality.

There are many reasons why utilities would differ in whether they decide to include a particular device in their commercial EE program portfolio. Each utility must judge the measure or program to be cost effective, given their specific regional context and climate and customer base. There are also multiple quantitative analysis methods that utilities may use to calculate program cost effectiveness, ranging from simple return-on-investment calculations to more complex calculations that seek to also account for benefits to society, such as environmental and non-energy benefits. The most common metric is the Total Resource Cost, or TRC, which is defined as the benefits of the measure or program (described as savings or avoided costs) over the cost of program materials and administration (See Appendix A for details of TRC calculation). Net positive programs are those that yield a score greater than or equal to one [29, 30]. Furthermore, many utilities also calculate program attribution (to address the free rider problem) using an additional calculation of the net-to-gross ratio. An independent evaluation of the relative program cost-effectiveness between utilities was beyond the scope of this project, and data published by utilities was inconsistent and incomplete. However, we did consider general program success on a heuristic basis, e.g., that programs that have been continued and built upon for multiple consecutive years would represent a value proposition, and thus a high return on investment for utilities.

Individual Device-based Programs

Standard Incentives

Energy efficient devices

One way utilities incorporate plug load devices into EE programs is through standard incentive programs. Standard incentive programs offer prescriptive incentive amounts or rates for pre-approved qualified products or behaviors, typically administered as rebates. Most standard incentives encourage customers to purchase more energy-efficient equipment, while others encourage purchase of control system devices (e.g., vending machine "misers") or networked computer power management systems. A summary of the standard incentives observed in the utilities in this study is shown in Table 3. This table compares our research on the 20 selected utilities to the plug load incentive database maintained by the Department of Energy [31]. Selected devices are discussed in more depth in this section.

Table 2. Standard Incentives

Device	**Selected 20 Utilities: Participating Utilities**	**Selected 20 Utilities: Incentive Amount**	**DOE Better Buildings Utility Database*: Participating Utilities**	**DOE Better Buildings Database*: Incentive Amount**
EE devices				
Computer, Desktop	0	-	4	$4-$12/device
Computer Monitor	0	-	1	$5/device
Computer, Laptop	0	-	0	-
Thin/zero client	1	$10/device	5	$5-$50/device

Printer/Copier	0		1	$10/device
Server	1	$100/device	3	$15-$200/device
UPS Units	2	$20/kW; $1,400-$4,000 (by size)	1	$55 per kW
Television	0	-	1	$150/device
Room AC	2	$25-$200/device	2	$25-$50/device
Dehumidifier	3	$25-$50/device	3	$10-$25/device
Cash Register	0	-	0	-
Residential Freezer	1	$50/device	2	$25-$200/device
Residential Refrigerator	3	$35-$150/by size (multi-family)	3	$25-$200 (by size)
Mini-Refrigerator	0	-	0	-
Commercial Freezer **	9	$35-500/device (ranges by size)	0	-
Commercial Refrigerator **	8	$45-400/device (ranges by size)	0	-
Residential Dishwasher	1	$50/device	2	$25-50/device
Commercial Dishwasher **	13	$50-$2000 (ranges by features, size)	2	$25-$50 (ranges by features, size)
Commercial Oven **	13	$170-$2,000/device (ranges by features, size)	0	-
Fryer **	12	$150-$750/device (ranges by features, size)	0	-
Hot Food Holding Cabinet	13	$200-900/device (ranges by size)	0	-
Griddle	13	$130-$650/device or $150-$200/linear ft.	0	-
Wrap Machine	4	$125-275/device	0	-
Steam Cooker	13	$750-$2500/device	0	-
Refrigerated vending machine	1	$50/device	0	-
Ice Machine	12	$50-$800 (varies	0	-

		on type, capacity)		
Water Cooler	1	$50/device	1	amount not available
Clothes Dryer	1 (heat pump)	$200-400/device	2	$50-$300/device
Commercial Clothes Washer	5	$20-$300/device (varies on features)	2	$50-$100/device (varies on features)
Residential Clothes Washer	3	$50-$65/device (multifamily)	1	$50/device
Pool pump (VSD)	4	$100-$600/device	0	-
Control devices				
Computer Power Management Software	3	$10/laptop; $10/monitor; $12-$20/desktop	13	Majority $9-10/device; range $4-$32/device
Advanced Power Strip, Tier 1	4	$4-10/device rebate or discount on marketplace	12 (plus 6 not specifying Tier 1 or 2),	Majority $10-15/device; range $1-$25/device
Advanced Power Strip Tier 2	0	-	5	$20-$50/device
Smart Plug	0	-	0	-
Plug Load Occupancy Sensor	1	$10/device	8	Majority $20/device; range $11-$25/device
Vending Machine Miser	7	$25-$150/device (higher for refrigerated)	96	$25-$150/device (higher for refrigerated)
* DOE Better Buildings Database consists of self-reported data for plug load device incentives (>150 utilities across the U.S.)				
** Programs for commercial food service appliances differentiate by major features, e.g., solid door versus glass door for refrigerators and freezers, or convection versus combination oven				

Results show strong consensus around offering standard incentives for many commercial food service appliances, albeit a wide range of incentive amounts. This reflects the higher up-front cost and larger energy consumption of these devices compared to other plug load devices on this list. Commercial kitchen energy consumption is on average 5 to 7 times higher per unit of floor area than other commercial sectors [32]. Energy-efficient equipment is even more expensive, making it more difficult for businesses to justify. The price differentials between standard kitchen equipment and ENERGY STAR models are generally large enough that even with expected cost savings through energy savings, substantial rebates are needed to incentivize them [33]. ENERGY STAR has recommended incentive amount ranges that they deem appropriate for commercial kitchen appliances. Likewise, clothes washers that are ENERGY STAR certified are about 25% more efficient and use about 45% less water than the standard models.

For major appliances such as clothes washers, clothes dryers, dishwashers, and refrigerators, few utilities offer incentives for residential grade appliances to commercial customers, even if they offer them to residential customers. Adding such incentives can potentially benefit small businesses with lower capacity needs, multifamily building owners furnishing apartments, and businesses using residential equipment in their staff break rooms.

Results also show consensus against using standard incentives to promote energy efficiency for office equipment such as computers, printers, and televisions. Computers (desktops and laptops) and monitors are some of the most prominent plug load devices consuming 10-20% of total energy consumption in commercial buildings [34]. Although ENERGY STAR versions of these devices exist, the generally modest amount of energy saved warrants an equally modest incentive, at best [35]. However, these incentives are quite small compared to the cost of the devices and are thus unlikely to motivate consumers. Also, the majority of products sold in 2018 were ENERGY STAR-certified products, especially in the imaging and notebook category [36]. At the same time, many businesses contain large numbers of these devices, and the small amounts of energy saved per device can add up, suggesting that they should not be ignored. Utilizing centralized power management software can save energy for a large number of computers, making incentivizing these systems through standard incentives cost-effective. NREL estimates suggest that enabling standby mode after 15 minutes of inactivity can save about 500 kWh/yr. per desktop computer [37]. Savings for these devices can also be enhanced by encouraging efficient use of power management settings and external control systems for computers and imaging equipment. Savings may also be incentivized in holistic programs by encouraging replacement of desktop computers with laptops or with thin clients. For instance, one study estimated that switching from desktops to thin clients results in a 66-73% reduction in annual energy consumption [38].

Room air conditioning (AC) units and dehumidifiers condition space in individual rooms, which can be an effective way to save energy when whole-building HVAC systems are not applicable or affordable. Room air conditioning units that are ENERGY STAR certified use 10% less energy on average [39]. In 2016, the DOE finalized new standards for dehumidifiers, which represent energy savings of about 15-25% [40]. Even among utilities that offer incentives for energy efficient options to their residential (and low income) customers, few offer the same incentives to commercial customers.

Heat-pump clothes dryers are a special case. While other major appliances have undergone significant energy efficiency improvements in recent decades, the energy wasted by electric clothes dryers has been consistent since the 1970s [41-43]. Heat pump dryers represent a major breakthrough, being both cheaper to run and gentler on clothes [44, 45]. As of 2020, ENERGY STAR offers a list of 10 dryers designated as "Most Efficient Products," all of which utilize heat pump technology [46]. Tests of heat pump technology in residential-grade dryers indicated they are 50%-60% more energy efficient than conventional dryers and about 47% more energy efficient than efficient electric dryers without heat pump technology (producing 333 kWh/year in energy savings) [41, 45]. Another evaluation concluded that hybrid heat pump dryers save 30% more energy than market average while heat pump dryers save 50% more energy. Moreover, conventional ENERGY STAR rated dryers saved 8% more on average than the market average. This report emphasized the significant energy savings opportunity (200kWh-600 kWh) available through integration of heat pump technology [47]. Only residential-grade heat-pump dryers are currently sold in the U.S. and only one utility in our study (Efficiency Vermont) includes it, but they offer incentives to both residential and commercial customers. Other, smaller utilities are moving forward with incentivizing heat-pump and hybrid heat-pump dryers, and we expect others to follow suit in the near future, as these devices further penetrate the U.S. market.

As major end uses become more efficient and pressures for additional savings increase, plug load devices that have more moderate savings potential may gain more attention, such as cash registers. Commercial retail sectors use point-of-sale equipment that needs a constant energy supply in order to function effortlessly for transactions. This equipment includes cash registers, demagnetizers, barcode scanners and scales, handheld barcode scanners, and conveyer belts. Combined, these devices can use 75–130 W. On average, point-of-sale equipment can cost $100/unit annually to power if left on continuously [48]. Upgrading cash registers to models with standby modes can save up to 222 kWh/year [49, Appendix 1]. Doing a walk-through of the facility to identify equipment that can be updated can save 30-40% on energy consumption [49]. None of the comparison utilities offer a standard incentive for cash registers. ENERGY STAR does not evaluate cash registers, despite the energy savings of models that include standby modes. We are not aware of any efforts in this area. In the meantime, utilities should ensure that facility assessments for relevant businesses include advice about upgrading cash registers and about using external plug load control strategies to ensure the devices are powered down outside of business hours.

Plug Load Control Systems

Another approach to reducing energy consumption in plug load devices focuses on power management: settings and external control strategies that transition devices into low-power modes when they are not being used. Many utilities in this study incentivize control strategies to reduce unnecessary energy consumption from plug loads, either through rebates or through offering the devices at a discounted price through an online marketplace. Monitoring studies in offices have found that most of plug load devices' wasted energy consumption takes place during nights and weekends, when buildings are unoccupied [9, 21, 50-52].This is a clear indication that investing in computers and other devices that have low-power modes, and ensuring that those settings are enabled, could save energy. Control devices with metering capabilities can have the added benefit of providing users with feedback about the device energy use and periods when energy is being wasted [53]. Control devices of any type should allow manual override to accommodate usage during atypical times [53] to avoid user frustration.

One type of control strategy is power management software for desktop computers, which monitors usage patterns and enters the device into low power mode when idle. Three of the utilities in this research incentivize power management software. Another strategy, particularly for devices that do not have this type of internal power management, is to use external control devices. The most common devices include advanced power strips (APS), occupancy sensors, and smart plugs. There are two versions of APS devices: Tier 1 and Tier 2. Tier 1 devices save energy by ensuring that peripheral devices (i.e., monitors, printers etc.) are switched off when the primary device (i.e., desktop computer) is switched off by the user. This prevents the peripheral devices from consuming “vampire”, or standby, power. We found that 7 out of 20 utilities currently incentivize Tier 1 APS devices. This strategy depends on the user to power down the primary device. Tier 2 APS are enhanced versions of Tier 1 devices and include occupancy sensors that track when the primary device has entered idle mode, and automatically powers down the primary and peripheral devices connected to the power strip [54]. Although none of our target 20 utilities offered incentives for Tier 2 devices, the DOE Better Buildings database lists some utilities that do. Smart plugs use internet connectivity to power down devices plugged into the outlet, primarily through mobile apps and voice control. Although we could find no utilities that currently incentivize these devices for the commercial market, they are a growing category in the residential sector, and many potential applications for commercial offices also exist.

Occupancy sensors are triggered when a person enters a room and activates the connected device. When no activity is sensed over a specified period of time, the sensor powers down the device. The most common use of occupancy sensors in commercial buildings are hard-wired lighting systems. However, a number of plug-in products are also compatible with occupancy sensors. For example, ComEd incentivizes passive infrared and ultrasonic plug load occupancy sensors to control plug load equipment with $10 per sensor. The sensor must be used to control equipment in offices and cubicles, including lighting, shared copiers, and printers [55]. We found that 8 out of 20 utilities in this study incentivized occupancy sensors.

Finally, specialty control devices, such as vending machine ”misers”, utilize occupancy sensors. Vending machine misers use a motion sensor to deactivate the lights and power down other systems when nobody is near, then activates the vending machine when somebody approaches it, saving energy while maintaining key elements of the machine's mechanical system [56]. NREL research indicates that employing load management devices on refrigerated vending machines can save about 950kWh/yr. per vending machine [37].

The savings of external control devices such as APS, motion sensors and misers, and smart plugs depends on how effectively they are installed and maintained by the user and which devices are controlled by the device. Given the variation in model designs and inconsistent terminology across brands, one challenge is effectively communicating to customers which devices qualify under the program. Another challenge is that such devices are deceptively easy to install incorrectly [6], resulting in no energy savings even though the devices appear to be functioning.

Online Marketplaces

Four of the 20 utilities encourage commercial customers to buy energy efficient devices and control strategies through online marketplaces. These marketplaces, maintained by the utility, sell small energy-saving devices directly to customers at discounted rates. As utilities are increasingly looking for new cost-effective measures, online business marketplaces represent a simple, yet profitable way of expanding program portfolios [57, 58]. Online marketplaces provide discounted products, including advanced power strips (both Tier 1 APS and Tier 2 APS), smart thermostats, smart home products, water-saving aerators, and lighting sold directly through the utility website. While such marketplaces are more often targeted to residential customers (true for 12 of the 20 utilities), they can be expanded to commercial customers as well. They may also benefit from including a wider range of control devices, as mentioned earlier. For example, a measure and verification study in 2019 showed Ameren Power's program (Illinois) to be highly successful. Based on the utility's net-to-gross ratio calculations, APS devices achieved 100% of the targeted energy savings, while the smart thermostat category achieved 101% of its energy savings goals and lighting savings realized 94% of its target [59].

A second approach is a brokering platform, which helps customers learn what types of products would work for them, which models are incentivized, and where to buy them. Brokering platforms are operated by third parties contracted by the utility, which provide lists of qualified products for their incentive programs along with product comparison tools for price and reviews, and links to retailers in the state that stock rebate-eligible products. Currently, no utilities offer the brokering platform for commercial customers, and are aimed instead at residential customers. However, several examples provide a possible roadmap for future commercial customer inclusion. Efficiency Vermont provides a page with product comparison tools for price and reviews, and links to retailers in the state that stock rebate-eligible products. Consolidated Edison (New York) provides comparison tools along with energy usage and product performance scores on its residential marketplace site.

Midstream Programs

Several utilities in the comparison study use midstream incentive delivery programs, especially for commercial kitchen appliances. The goal of the midstream program design is to encourage market transformation by targeting suppliers, distributors, and retailers. By influencing purchasing decisions of energy-efficient products throughout the supply chain, the product choice set for end customers will tend to become more energy efficient over time. Midstream incentives are generally paid to the supplier or distributors when they select specific approved models for their inventory. Ten of the utilities examined here offer or are pilot testing midstream incentive programs for commercial food service equipment to commercial customers, (ComEd, Focus on Energy, PG&E, SCE, Consumers Energy, SMUD, SDG&E, and Efficiency Vermont).

Although midstream programs do not always require distributors to pass point-of-sale discounts directly to customers, most of the utilities in our comparison study do specify end-use customer incentive amounts. Another type of midstream model offers incentives to individual sales representatives to motivate them to promote energy-efficient equipment; the aim is to disrupt the status quo practice of highlighting the lowest-cost products to customers. For example, PG&E and National Grid offer pre-approved sales commissions (known as "spiffs") to sales representatives at participating distributors for each qualified energy-efficient kitchen product they sell [60, 61].

Best practice research stipulates several characteristics that make technologies and products successful in midstream incentive delivery: the product must constitute a defined market, be cost-effective for long-term energy savings, and produce enough energy savings to merit start-up program costs [62]. Many plug loads, particularly commercial kitchen equipment, meet these criteria. Kitchen equipment is a good category to initially target to midstream programs, because they are more costly and produce greater energy savings than most other plug load categories and yet, like other plug loads, these devices are generally easy to self-install and do not require the deep infrastructure integration that HVAC equipment does. For example, ovens, fryers, refrigerators, and dishwashers are easily exchanged, and require minimal building integration during installation.

Holistic Programs

Custom Incentives

Most utilities (12 out of 20) in the study group also offer their commercial customers custom incentive programs that are based on energy efficiency performance of installed measures, selected on an a la carte basis. Whereas standard incentives offer a set rebate or discount for investing in a particular energy efficient solution, custom incentives are based on results. Custom incentive programs allow the utility customer to develop a tailored energy-efficiency plan for their facility which is evaluated and approved based on the expected energy savings and costs. This gives business customers a wide selection of options that are flexible enough to meet their unique needs. However, this process typically requires the involvement of an energy advisor and a complex application process. By comparison, the clear-cut nature of standard incentives makes the application process easier, faster, and more predictable for customers, and thus appeal to those who may not have the time or resources to commit to a full custom program.

Small Business Programs

Almost all of the comparison utilities (19 out of 20) offer some type of small business incentives package. In practice, this covers most utility customers. For instance, ComEd defines eligibility for "small commercial" as up to 100 kW peak demand, which includes 95% of their commercial customers. Small business program participation typically begins with a free in-person facility assessment conducted by a utility-approved contractor. The service provider installs no-cost "direct install" measures, such as showerheads, bathroom and kitchen faucet aerators, Tier 1 APS, and vending misers [63]. The assessment results in a comprehensive report including specific recommendations for EE measures and projects. Customers then choose which projects they wish to pursue, and the service provider offers full installation services. Assessment paired with direct install offers robust opportunities to effectively integrate plug load control strategies into energy efficiency efforts. Depending on the types, locations, and usage patterns of their equipment, some businesses will benefit more from load-sensing Tier 1 APS devices, while others will benefit more from timer-based APS devices, Tier 2 APS devices, or occupancy sensors.

Addressing plug loads in offices is especially important. Offices use a wide range of plug load products, such as computers, monitors, projectors, TV screens, shredders, printers, and multifunction devices (combining printing, scanning, and copying). Previous California Energy Commission research shows that such devices cumulatively waste considerable energy by being left on when not used, especially overnight and on weekends [28]. Energy Trust OR offers a program specifically targeted at small offices that provides measures for lighting, lighting controls, APS devices, power management software, and data server measures such as UPS and mini-split air conditioning units for server closets. Energy Trust OR also offers this program on a tiered scale, offering greater incentives for more complex and integrated projects

Many utilities also offer small businesses free self-install kits that include devices such as Tier 1 APS devices, smart plugs, lighting measures for small offices, and faucet aerators and pre-rinse spray valves for food service customers. These programs allow an easy first step to engage customers and provides an introduction into further EE programs. However, the gesture could potentially backfire if customers do not actually use the free devices.

Plug Load Education and Training

Many utilities provide educational materials on their website on efficient plug load equipment and control strategies. For example, BGE explains the rationale of offering incentives for smart power strips and other plug load measures. Efficiency Vermont explains various measures, such as APS, energy-efficient computers and monitors, and data center efficiency. Mass Save (Eversource MA, National Grid) addresses, among other things, the rationale of using vending machine misers. The Business Energy Advisor library (offered by FPL, Georgia Power, and We Energies) describes plug load technologies and offers savings tips for a variety of business types.

Facility assessments often focus on large energy end-uses, but they can be an excellent opportunity to encourage customers to reduce plug load energy consumption. For example, ComEd's facility assessment program offers no-cost and low-cost measures to increase the operational efficiency of existing equipment at the site [64].

Emerging Areas of Research

Grid-Interactive Efficient Buildings

"Smart" buildings are an emerging target for EE programs, spurred in part by the growing need for flexible grid management to handle an increasingly dynamic distribution of energy resources. While definitions of this emerging technology are constantly evolving, the key feature is deploying building-wide energy management systems (EMS) that allow holistic internal control of multiple systems and enable dynamic external interactions with the energy grid. The ultimate goal of the GEB is to integrate energy efficiency, demand response, distributed generation sources, EVs, and energy storage measures into a holistic, synergistic system of energy management and savings [65, 66].

GEB technology is still in early stages of development. GEB-related initiatives offered by the utilities studied here currently exist as enhanced automatic demand response (ADR) programs. These programs incorporate EE measures into existing demand response programs and use advanced metering infrastructure (AMI) technology to identify energy waste and suggest upgrades. For example, PG&E offers to install efficient equipment for large commercial customers if done in conjunction with enrollment in their ADR program. The Real Time Energy Management program, offered by the New York State Energy Research and Development Authority, promotes a GEB prototype system that collects real-time–smart meter data from commercial, industrial, and multifamily buildings. Data analytics software performs assessments of the participating properties and generates information on energy optimization opportunities for each site [66].

EV Chargers

Over half of the comparison utilities encourage commercial customers who own or operate parking spaces to help expand infrastructure for EVs through EV charging station host programs (ConEd, Consumers Energy, Eversource MA, Georgia Power, National Grid, NYSEG, PG&E, SCE, SMUD, and Xcel Minnesota). This measure affects a wide range of commercial customers, including retail businesses, office buildings, universities, government buildings, and large multifamily residences. The customer initiates program participation by submitting an application. If accepted, the utility visits the property to conduct a consultation, assessing a suitable location for installation. The customer purchases the charger(s) from a vendor qualified by the utility. Note that for many utilities, such as Eversource MA and National Grid, the customer is responsible for the cost of the charging station and initial installation. After sending in proof of purchase, the utility takes on all infrastructure work to connect the charging station to the grid. The utility generally pays for 100% of the consultation and grid infrastructure requirements (e.g., laying new line). Utilities also provide coordination assistance to complete permitting paperwork and equipment inspections (for example, Eversource MA, SCE, National Grid).

Key Findings

We found that successfully implementing plug load EE incentives for commercial customers is often a multifaceted task, that needs to consider not only individual devices, but also information about the customer industry sector, user and building manager behaviors and needs, and technical requirements of individual offices, commercial kitchens, and other commercial buildings. We recommend a multipronged and targeted approach for standard incentives, starting with device upgrades that yield high returns on investment in energy savings and utility bill costs over time. One method that many utilities are piloting is the midstream incentive program for commercial kitchen products, which not only seeks to yield energy savings for the customer and utility, but also aims to transform the availability of products on the market.

Furthermore, individual device incentives should be informed by whole-building energy saving strategies. For example, we do not recommend incentivizing mini refrigerators to commercial customers, as energy efficiency models do not represent large savings, and much higher savings can be achieved by replacing personal office refrigerators with shared full-sized models. Removing underused full-sized refrigerators can save up to 400kWh/yr. per device, and consolidating personal mini-fridges into one full-sized shared refrigerator can save 350kWh/yr. per mini-fridge removed [67]. Additionally, some relatively low-tech devices can be incorporated into incentive programs to better support hard-to-reach customers. For example, we recommend further exploration of incentives for commercial room air-conditioning units, particularly as these devices may benefit small businesses, particularly those who rent space in older buildings and/or in disadvantaged communities.

Similarly, self-install control devices should be paired with informational materials and targeted at more IT-savvy customers, while other customers should be guided toward control device use through interactions with utility advisors and facility assessments. For example, when selecting devices for inclusion in free small business kits, we recommend that utilities design kit combinations that target specific plug load control device(s) to business type (e.g., office, retail, grocery) and offer clear instructions on use.

Our assessment of how utilities managed custom incentive programs suggested to us that holistic custom incentive programs (including training of utility staff) should clearly link to those plug load devices that are covered under standard incentives as alternatives. However, within the custom incentive programs, more efforts could be made to identify plug load alternatives whose smaller savings do not individually merit large standard incentives but that can, in the aggregate, sum to substantial savings. We envision a two-tiered system of evaluation, where standard incentives would be recommended for qualified plug load products for initial or low-investment approaches, while for those customers pursuing larger renovations involving custom incentives, utilities would recommend including a wide range of plug loads, particularly those that are hard-to-reach (e.g., specialized and/or custom equipment for specific industries and applications).

Successful implementation and maintenance of savings from EE programs is further underpinned by education and training of technicians and users. Based on best practices in the field, we recommend training technicians to identify and solve specific plug load devices inefficiencies in facility assessments and EE project recommendations, including determining which type of plug load control strategy is appropriate for the situation. Technicians could demonstrate how exactly to set up an APS or occupancy sensor with a range of devices, and how to check whether multiple types of devices have their standby modes activated. Training and outreach should extend to all stakeholders, including building occupants as well as building managers, IT managers at data centers, and distributers involved in midstream programs. In addition to facility assessments, courses and demonstrations could be held at the utility's sites or remotely.

Finally, investing in up-and-coming technologies, such as EV chargers and GEBs helps to future-proof the utility for the shifting energy policy landscape, which will continue to evolve towards the direction of distributed energy resources (DERs), flexible load and demand side management, and trends in connectivity and the Internet of Things (IoT).

Barriers

Plug Load Diversity

The wide range of plug load devices and the diversity of the commercial sector make it difficult to design programs that are effective for multiple types of businesses. Other types of EE programs apply very broadly, as every building needs lighting, HVAC, and envelope measures such as insulation and windows. But plug load devices--such as printers, ovens, cash registers, and clothes washers--are more specialized and thus have more limited application. As devices do not fit into every program type, utility programs need to take more care to correctly align each device with specific measures that fit the targeted customers.

Plug Load Functionality

Plug loads have unique operational characteristics that make them harder to target in EE programs than HVAC and lighting measures. Individual plug load devices do not use much energy, but the waste accumulates over large numbers of devices. Limited savings per device and relatively short product lives translate to low incentive amounts, which can be discouraging for utilities and customers.

Most plug load devices involve a close level of user involvement, and any perception that energy-efficient appliances translate to a lower quality user experience can be problematic. For instance, energy-efficient dryers and dishwashers have longer run cycles than traditional appliances. Particularly for devices operating in commercial settings, longer operation times can be a strong negative factor. This disadvantage must be outweighed, along with the higher cost, to persuade the customer to purchase energy-efficient options.

There are also special considerations for plug load products when integrated into GEB and ADR programs. Few plug load devices can have their power cut without complete loss of functionality. Users expect devices like computers, projectors, copiers, and cash registers to function whenever needed. Refrigerators and freezers also have physical limitations for load shift and shed without risking food spoilage. Smart connected solutions promise to link up webs of devices, sensors, and energy monitors, but this has not been realized yet. The connectivity features in smart connected devices and appliances do not necessarily save energy; worse, they require a concurrent overhead energy demand for cloud computing needs. Meanwhile, the behavioral strategies that connected devices do enable only save between 3-6% energy over baseline, which is similar to savings that can be achieved by purely behavioral interventions. Finally, interoperability problems--between smart connected devices at the building level and between utility protocols at the grid level--need further resolution before comprehensive GEB programs can achieve goals; GEB programs available in some utility service areas today are largely ADR programs with some integration of energy-efficient building controls and sensors.

Behavioral Barriers

For many plug loads, user behavior greatly impacts the device’s ability to save energy. Factors such as selecting temperature and speed settings, load type, and load size greatly influence the ability of some appliances (such as heat pump dryers and dishwashers) to achieve the energy savings promised by the device. Other devices require users to pro-actively enable power management settings, or at least comply by not disabling default settings, to ensure that devices transition to standby mode when not used. Customers generally prioritize energy efficiency rather low in purchasing decisions unless it is connected to saving money. It can be difficult to communicate and convince individual businesses about the importance of reducing plug load energy use at the aggregate building level. In the absence of clear measurement and feedback mechanisms, energy use is invisible in everyday life, and most people are unaware or misunderstand how much energy is used by personal devices in office spaces such as mini-fridges and desktop computers. Similarly, CFS customers and distributors are poorly informed on the energy-saving benefits of ENERGY STAR equipment. Even IT managers, who are experts about computers and data centers, may dismiss or overlook the energy use of these devices.

Changing behavior is generally approached by providing clear information about what to do and motivation about why to do it: in EE programs, this means improving educational resources and incentives. Although education about how to achieve plug load energy savings is universally needed for all business types, the kind of comprehensive training that is required is difficult to provide to each individual business due to the variability of businesses in the commercial sector.

Website interface also has an important impact on customer engagement. This is especially important for promoting information on saving energy with plug load devices, as few customers are even aware of plug loads or plug load controls as device categories and are unlikely to be actively seeking them. Any lack of consistency or problems with navigating across website pages can confuse users and hinder program participation.

Financial Concerns

ENERGY STAR-certified equipment and other energy-efficient options can be much more expensive than alternatives. Furthermore, researching the types of energy-efficient appliances that might be cost-effective for a specific organization, building, or operation takes time. Money and time constraints are common barriers to major investments such as data center hardware and commercial food service equipment, especially for small businesses. Pressures on short term cash flow can prevent customers from investing in energy efficient upgrades, even if it would save money in the medium to long term. For example, low profit margins in the CFS industry leads to replacing equipment only on burnout, which can result in buying the least expensive option that is immediately available. In response, the suppliers and distributors who compete for their business tend to stock older models and refurbished equipment, which are less expensive but also less energy efficient. Similarly, heat pump dryers are considerably more expensive than conventional products, which may inhibit their uptake in commercial laundry facilities, multi-resident apartment buildings, and institutional settings such as hospitals, assisted living, and universities. In terms of power management strategies, Tier 2 APS devices cost more than Tier 1 APS devices, which may discourage businesses from using Tier 2 products, even when their facilities would be more suited to these more sophisticated devices.

Conclusion

In this research, we have assessed the state of the art in commercial utility programs in the U.S. and identified opportunities for improving their inclusion of plug load savings. As lighting and other major end uses such as HVAC become more efficient, plug load energy consumption is garnering attention as an emerging program category. All utilities in the study have measures in place to reduce energy use from certain appliances and electronics. However, some plug load strategies are more effective best practices, such as offering an increased variety of standard incentives for highly efficient "big ticket" products (e.g., commercial kitchen appliances), incentivizing and advising on low-cost solutions for energy management (e.g., APS devices, smart plugs, and power management software), and offering a robust combination of direct install, midstream, and online marketplace programs. Since plug load energy consumption also depends heavily on user behavior, we recommend addressing both technical and educational approaches for improving program engagement.

Finally, we also identified several key barriers to reducing plug load energy consumption through utility EE programs. These barriers broadly include plug load diversity, plug load functionality issues, behavioral barriers, and customers' financial concerns.

Appendix A: TRC Calculation

$$\mathrm{TRC} = \frac{\mathrm{Benefit}}{\mathrm{Cost}} = \frac{\mathrm{UAC_t + TC_t}}{\mathrm{PRC_t + PCN + UIC_t}}$$

	Variables	Definition of Variables	Explanation
Benefits	UACt	Utility avoided supply costs in year t	The avoided supply costs should be calculated using net program savings, savings net of changes in energy use that would have happened in the absence of the program.
	TCt	Tax credits in year t	Any state or federal tax break considered a reduction in the costs test. The inclusion of tax credits or incentives depends on the region considered
Costs	PRCt	Program Administrator program costs in year t	Overhead costs are administration, marketing, research and development, evaluation, and measurement and verification
	PCN	Net Participant Costs	Participant cost = measure cost - participant incentive Can be incremental or total costs, depending on age of pre-existing equipment (i.e., replacing older equipment at the end of its EUL usually uses incremental cost for the new measure)
	UICt	Utility increased supply costs in year t	The costs in this test are the program costs paid by both the utility and the participants plus the increase in supply costs for the periods in which load is increased

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