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Review

# Review of EU product energy efficiency policies: What have we achieved in 40 years?

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ABSTRACT

The improvement of energy efficiency of products is a key pillar of climate and energy strategy in the European Union (EU). The first EU product policies were adopted in the late 1970s, and they have evolved to become a coherent set of implementing measures under framework directives that harmonise and refine the regulatory process. After years of weak implementation, considerable progress in terms of scale and ambition has been achieved in the last decade. In 2020, product mandatory measures covered 50% of the EU total final energy consumption, leading to 46 Mtoe energy savings. This paper describes the available policy instruments to promote energy efficiency and remove the market barriers hindering the penetration of the best performing technologies. It offers a review of the progress made over these last 40 years of EU product policies, describing the Energy Labelling, the Minimum Energy Performance Standards (MEPS), the Ecodesign Directive and the voluntary agreements (EU Ecolabel and Green Public Procurement). Moreover, it highlights the remaining challenges and provides policy recommendations to further exploit the EU potential to save energy from products.

## 1. Introduction

In the global fight to limit climate change, the European Union (EU) achieved important reductions of its $CO_2$ emissions of 45% in 2019 compared to 1990 figures (IEA, 2021). However, further efforts are needed to be in line with the Paris Agreement (Skjærseth, 2021) and to reach climate neutrality by 2050. As indicated in the EU Green Deal, EU policies aim at a renewables-based energy supply, as well as the decarbonisation of the industry, transport and building sectors, combined with decreasing consumption by improving energy efficiency and promoting sufficiency, so far the main drivers of emissions reductions (González-Torres et al., 2021a). In 2018, the European Commission (EC) adopted the Energy Efficiency First Principle, to emphasise the role of energy efficiency as one of the key pillars, not only to meet the climate target, but also to reduce the dependence on fossil fuels and improve the security of supply (European Parliament and Council of the European Union, 2018). Energy efficiency is a long-standing priority for the EU and has been addressed by policies for over 40 years, since initial efforts emerged in the 70s as a response to the 1973 oil embargo to guarantee energy security and reduce import dependency (Economidou et al., 2020).

Energy efficiency improvements can be achieved by targeting every stage of the energy chain: in the energy sector during the extraction, transformation and distribution of the resources, and in the demand side by the enhancement of end-use technologies (González-Torres et al., 2021b). The focus on end-use technologies is of great interest, as they were responsible of 67% of the primary energy consumption in 2020 (Fig. 1). Thus, product policies addressing their energy efficiency have a large potential, and allow for the introduction of cross-cutting measures that tackle most energy use. To date, the EU legislation has covered products mainly in the buildings sector, but also in the industry and transport[1] ones. Altogether, the legislated products account for half of the final energy consumption.

Advantages related to energy efficiency in products are numerous according to the literature. In addition to the environmental benefits regarding its contribution to meeting climate and energy targets, it can also preserve natural resources and reduce local pollution (Wiel and McMahon, 2003). Moreover, it impacts the market, by promoting

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[1] Note that $CO_2$ requirements in the transport sector are not addressed in the document, as they are the subject of a different policy. The product group here covered is 'tyres', whose performance affects energy consumption in vehicles.

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competitiveness and innovation (Braungardt et al., 2014) and positively affecting both consumers and suppliers (Kiling et al., 2021; Papadoyannakis, 2006; Polverini and Miretti, 2019). If well informed, consumers' purchasing decisions are oriented towards lowering energy use over products' life cycle, thus leading to monetary savings that could also tackle energy poverty and improve indoor environment quality. Products suppliers could benefit from increased prices for more environmental friendly products, and their improved corporate image could result in higher volumes of sales and revenues (Plouffe et al., 2011) as well as job creation. For these reasons, product policies prove to be highly cost-effective (IEA/4E TCP, 2021) and very useful for decoupling energy and resources consumption and economic growth.

However, some barriers hinder the penetration of efficient technologies (Jollands et al., 2010). At international level, there is a lack of funding to support efficient products innovation and of collaboration between industrialised and developing countries that delays the spread of technology across borders. At national level, authors outline the lack of manufactured or imported efficient products, as well as the lack of institutional capability to develop policies, inform consumers and distribute financial resources (Levine et al., 1995). At a lower level, consumers seem to neglect the cost-effectiveness of the investment on efficient products (Heutel, 2019) and they find difficulties to financing the initial investment (Wilson et al., 2015). Furthermore, they lack understanding and time to make informed decisions based on the life cycle costs[2] (Joshi et al., 2019). Finally, split incentives in the building sector, also referred to as the "principal-agent" problem (Satthaye and Murtishaw, 2006), could lead to inefficient practices as the costs of the product-use and product-acquisition are not held by the same person (McAllister and Nase, 2023). This could happen when the tenant is not responsible for paying the energy bills, or when the investment decision is made by a property developer who will not benefit from the advantages of reduced energy bills as it is usually the case of heating appliances (Kelly, 2012).

Market competition alone cannot overcome these barriers to achieve the high penetration rates of the most efficient products. Lessons learnt from the market transformation, due to technological progress of certain products, show that low-cost options remain in the market even when more efficient solutions are introduced through innovation (e.g. incandescent light bulbs). Geller & Nadel (1994) described the process with an S-shaped logistic diffusion curve (Fig. 2). As research introduces new

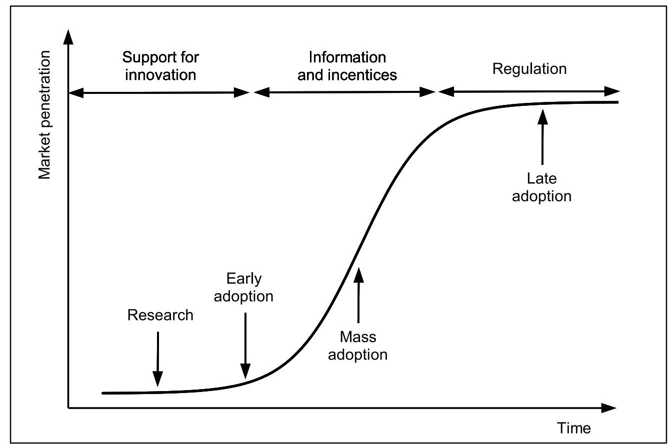


**Fig. 2.** Market transformation as innovation and appropriate policy support. Source: Rosenow et al. (2015).

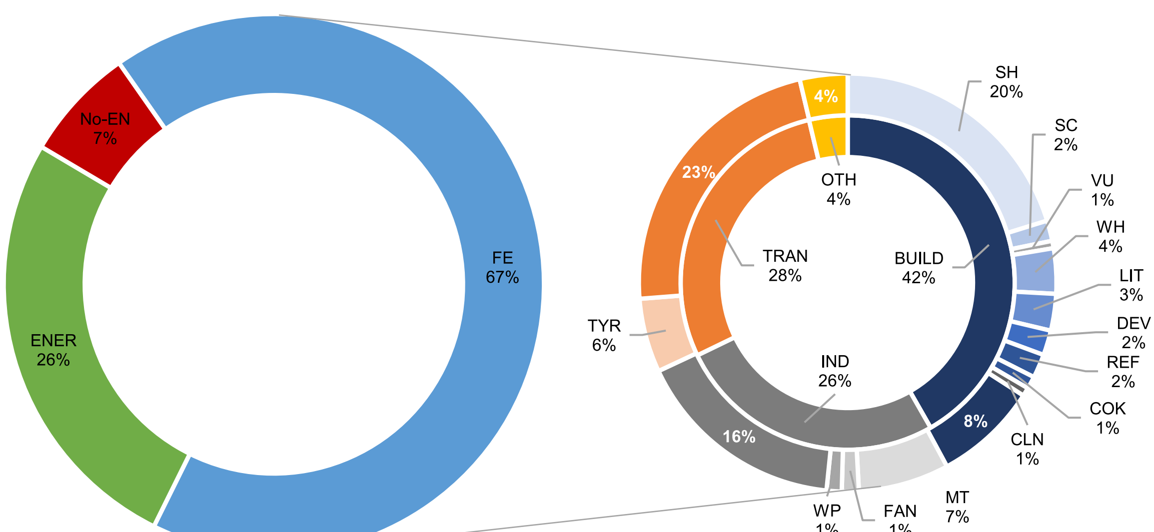


**Fig. 1.** Primary and final energy consumption by sectors and by main products covered by EU product policies in 2020.
On the left, primary energy supply disaggregated in final energy consumption (FE), energy sector (ENER) and non-energy consumption (No-EN). On the right, final energy consumption disaggregated by sectors and main products: space heating (SH), space cooling (SC), ventilation (VU), water heating (WH), lighting including stand-by (LIT), electronic devices (DEV), refrigerators and freezers (REF), cooking appliances (COK) and cleaning appliances (washing machines, driers, dish washers, vacuums) (CLN) in Buildings; electric motors (MT), fans (FAN) and water pumps (WP) in Industry; and tyres (TYR) in Transport; other sectors such as agriculture, fishing and forestry (OTH). Sources: Eurostat (2022) and EIA (European Union, 2021).

technologies in the market, penetration slowly begins, driven by early adopters to then 'take-off' as the awareness of the technology and its advantages spreads. Thereafter, the adoption continues but slows down until the full market potential is reached. Government intervention through product policies is necessary to accelerate and extend market transformation (therefore moving the curve leftwards and upwards), as they can shorten the diffusion period to the full utilisation of the new

[2] Note that 'Life Cycle Cost' is the approach that assesses the total cost of the product over its life cycle, i.e., the initial investment cost, the maintenance and operating cost and its end-of-life value; while the 'Life Cycle Analysis' evaluates the environmental impact through its life cycle, i.e., resource extraction and processing, manufacturing, distribution, use, recycling and final disposal.

products as well as increase the market penetration well beyond the full market potential (Rosenow and Kern, 2017). First, R&D measures to support innovation and market or bulk purchase programmes to facilitate commercialisation would allow the early introduction of new technologies. Second, incentives and information, such as energy labels, would stimulate early adopters and accelerate the adoption. Finally, regulation would eliminate inefficient technologies and practices by introducing minimum requirements to increase overall penetration. More sophisticated models based on evolutionary economics also link technological transition to multi-actor networks involved in socio-technical regimes (Geels, 2002), reaffirming that technical trajectories are not only influenced by designers and engineers, but also by users, societal groups, suppliers, scientists, capital banks, policy makers, etc.

Among the first governments to introduce product policies, the United States (US) (Geller, 1986), prompted by the oil shock, stands out for implementing the earliest energy efficiency standards that drastically affected manufacturers and significantly reduced consumption (IEA, 2000). The first concrete proposals were made in California, and mandatory standards were adopted at federal level and in several states between 1975 and 78 (Lenssen, 1990). Moreover, US enacted the first mandatory labelling program in 1975, the EnergyGuide (US Federal Trade Commission, 2022), which took effect in 1980 for major household appliances.

The EU also introduced early product policies in the 1970s to cap consumption; however, they resulted to be weak, poorly implemented and had a very limited scope (Waide et al., 1997). The evolution of such policies has been scarcely discussed in the literature. Some studies have focused on EU instruments individually, and they rarely addressed the complete picture of the current regulation (Calero et al., 2014). Additionally, mechanisms in other countries have been analysed, such as the Japanese Top Runner scheme (Siderius and Nakagami, 2013), US programmes (Banerjee and Solomon, 2003; Rosenquist et al., 2006) like the Energy Star labels, labelling and standards in Australia (Harrington and Wilkenfeld, 1997) or Brazil (Nogueira et al., 2015), etc. There have also been reviews and reports on international comparisons of programmes (Mahlia et al., 2002; Shi, 2014; Turiel, 1997; Turiel et al., 1997), but the complexity and changing nature of European policy has not allowed for a comprehensive review of the history of EU product policies. To fill this gap, this paper analyses the policy instruments used and how they have evolved over 40 years of European products regulation. These regulations target technology in every consuming sector except transport, which is addressed by an independent and mature legislation.

The paper starts with a description of the methodology (section 2), followed by a classification and definition of the available instruments to promote energy efficiency in section 3. Then, the main EU policies are described (i.e. Energy labelling, Minimum Energy Performance Standards, Ecodesign Directive, Ecolabel and Green Public Procurement), examining the strengthening of their requirements and the extension of their scope (section 4). A discussion of their effectiveness, limitations and open issues follows in section 5, to shed light into future policy actions. Finally, conclusions and policy recommendations are drawn in Section 6.

## 2. Methodology

In order to comprehensively investigate product policies in the EU, an extensive literature review has been performed to collect and analyse publications on the topic, including definitions, descriptions, typologies, assessments of their effectiveness and criticism of their implementation. The review has been based on the Web of Science and the Scopus databases, covering the following particular topics and subtopics:

Topic 1: Market transformation and technological transition:

- Advantages of efficient technologies
- Barriers for their penetration
- Market dynamics

*Topic 2: Policy instruments*:

- Incentives
- Information: energy labelling
- Regulation: minimum requirements

Topic 3: Product policies in Europe:

- Energy labelling Directive: Framework and Implementing Measures (IM)[3]
- Minimum Energy Performance Standards (MEPS)
- Ecodesign Directive: Framework and Implementing Measures
- EU Ecolabel
- Green Public Procurement (GPP)

Topic 4: Others:

- Test protocols
- Ecodesign and circular economy.

Table 1 summarises the main references reviewed and classifies them in order to guide readers. In addition, the frameworks and implementing measures in Tables 3 and 4 in the Supplementary Information have been studied. These tables include the definitions of the product groups, the date of the first regulation, the framework directive under which the groups are regulated and the Implementing Measures in force, the amendments and the repealed ones. Furthermore, this review also draws on the insight knowledge and experience of one of the authors, who was involved in the policy making of the EU early product's legislation.

## 3. Available policy instruments

In order to promote energy efficiency and remove the barriers hindering the penetration of efficient technologies, several policies have been adopted worldwide. Despite slight differences in the proposed categorisations of these policies (Bertoldi, 2022), there is broad agreement among scholars in the following overarching categories: (1) financial and fiscal, (2) market-based, (3) information and awareness, and (4) regulatory instruments.

First, financial and fiscal instruments modify prices and costs to attract consumers' attention towards efficient products (through loans, grants and subsidies) and discourage inefficient purchases (through taxes) (Bertoldi et al., 2021). They must be designed to avoid, as much as possible, benefiting free riders, i.e., customers who would have bought efficient products in any case. However, there is no financing mechanism at EU level to specifically promote energy efficient products. Instead, fiscal instruments (e.g. tax rebates, direct tax deductions, and exemptions) are implemented at Member State level, mainly to comply with the Energy Efficiency Directive (EED) (Rosenow and Kern, 2017).

Second, market-based instruments incentive companies to promote technological innovation. As financial and fiscal instruments, they can do so through subsidies and taxes, and they should also try to avoid benefiting free-riding manufacturers, who would have produced efficient products in any case. For instance, the White Certificates schemes and obligations impose penalties on energy suppliers who fail to meet the mandated targets for energy savings through energy efficiency measures towards end-users. Penalties are also applied to car manufactures which fail to meet the fleet efficiency targets. In the EU, they

[3] The term *Implementing measures* (IM) is used in EU law to refer to legally binding acts of the European Union which are directly applicable in all Member States and do not need to be transposed into national legislation. Ecodesign requirements and Energy Labelling thresholds for specific product groups are established in *Implementing measures* that supplement the corresponding Framework Directives.

**Table 1**
Literature reviewed on product policies.

| Topic | Subtopic | No. of papers | Source |
|---|---|---|---|
| 1 | Advantages of efficient technologies | 8 | Braungardt et al. (2014), Economidou et al. (2020), Kiling et al. (2021), Papadoyannakis (2006), Plouffe et al. (2011), Polverini and Miretti (2019), Russo et al. (2018), Wiel and McMahon (2003) |
| | Barriers for their penetration | 7 | Bansal et al. (2011), Heutel (2019), Jollands et al. (2010), Joshi et al. (2019), Kelly (2012), Levine et al. (1995), Wilson et al. (2015) |
| | Market dynamics | 11 | Boardman (2004), Geels and Schot (2007), Geels (2002), Geller et al. (2006), Geller and Nadel (1994), Mahlia (2004), Rosenow et al. (2015), Rosenow and Kern (2017), Ruby (2015), Waide et al. (1997), Wiel and McMahon (2003) |
| 2 | Incentives | 5 | Bertoldi et al. (2010), Kelly (2012), Mahlia et al. (2002), Rosenow and Kern (2017), Zhong and Wang (2022) |
| | Information: energy labelling | 11 | Boardman (2004), D'Adda et al. (2022), Holt et al. (2000), Huse et al. (2020), Kelly (2012), Mahlia (2004), Mahlia et al. (2002), Rosenow and Kern (2017), Turiel et al. (1997), Wiel and McMahon (2003), Zhou et al. (2011) |
| | Regulation: minimum requirements. | 10 | De Almeida et al. (2008), Holt et al. (2000), Kelly (2012), Kengpol and Boonkanit (2011), Nadel (2002), Mahlia et al. (2002), McMahon and Turiel (1997), Pérez-Lombard et al. (2011), Waide et al. (1997), Zhou et al. (2011) |
| 3 | Energy labelling Directive: Framework and Implementing Measures | 20 | Alborzi et al. (2017), Andor et al. (2019), Bertoldi et al. (2006), Berwald et al. (2019), Bjerregaard and Møller (2019), Boardman (2004), Boyano et al. (2020), Calero et al. (2014), European Court of Auditors (2020), Faure et al. (2021), Goeschl (2019), IPSOS and London Economics (2014), Michel et al. (2015), Russo et al. (2018), Siderius et al. (2012), Stasiuk and Maison (2022), Stawreberg and Wikström (2011), Winward et al. (1998) |
| | MEPS | 6 | Bertoldi et al. (2006), de Almeida et al. (2017), Nadel (2002), Turiel (1997), Wiel and McMahon (2003), Waide et al. (1997) |
| | Ecodesign Directive | 23 | Bertoldi et al. (2006), Bovea and Pérez-Belis (2012), Bundgaard et al. (2015), Bundgaard et al. (2017), Calero et al. (2014), Cellura et al. (2014), CSES et al. (2012), Dalhammar (2016), European Court of Auditors (2020), Hansen et al. (2005), Hinchliffe and Akkerman (2017), Kemna (2011), Kiling et al. (2021), Labouze et al. (2003), Maitre-Ekern and Dalhammar (2016), Malcolm (2011), Mathieux et al. (2020), Papadoyannakis (2006), Pollex (2021), Polverini and Miretti (2019), Polverini and Tosoratti (2017), Rosenow and Kern (2017), Siderius and Nakagami (2013) |
| | Ecolabel | 2 | Bertoldi and Atanasiu (2008), Calero et al. (2014) |
| | GPP | 2 | Calero et al. (2014), European Union (2016) |
| 4 | Test protocols | 7 | Hughes (2017), Meier and Hill (1997), Spiliotopoulos et al. (2019), Stawreberg and Wikström (2011), Turiel (1997), Turiel et al. (1997), Waide et al. (1997), |
| | Ecodesign, circular economy, Life Cycle Assessment (LCA) | 17 | Ahmad et al. (2018), Bodova (2017), Castellani et al. (2021), Dahmani et al. (2022), Dalhammar (2016), Hughes (2017), Karlsson and Luttropp (2006), Mendoza et al. (2017), Marrucci et al. (2019), Mathieux et al. (2020), Patra (2021), Pigosso et al. (2015), Rheude et al. (2021), Rossi et al. (2016), Sierra-Pérez et al. (2021), Spreafico (2022), Thakker and Bakshi (2022) |

have been adopted in certain Member States, such as the United Kingdom (UK) (2002), Italy (2005), France and Netherlands (2006) (Bertoldi et al., 2010).

Third, information and awareness instruments aim to provide consumers with important product attributes, such as energy efficiency grades, influencing their choices and behaviours. They include information campaigns, trainings and consumption feedback through smart meters and bills, whereas they particularly target products efficiency through energy labelling schemes. Energy labelling consists of affixing information on products describing their performance (Wiel and McMahon, 2003), helping consumers to make the best purchasing decisions based on the trade-off of product attributes (D'Adda et al., 2022), e.g. balancing operational and upfront cost. They also have an important role in innovation, as they encourage manufacturers to produce more efficient, and thus better labelled products, than the competitor ones (Bertoldi, 2020).

However, the definition of performance is ambiguous (Pérez-Lombard et al., 2013). Amaratunga and Baldry (2002) defined it as the 'manner or quality of functioning'. Manner of functioning denotes operating in a particular way to accomplish a task or function (efficacy synonym), while quality introduces the nuance of the degree of excellence or success in the achievement of that task (efficiency synonym). Additional confusion has been introduced in Europe by the Energy Performance of Buildings Directive (EPBD) (Directive, 2002/91/EC) (European Commission, 2002a), where energy performance is defined as 'the amount of energy actually consumed or estimated … ' which is indeed an energy use figure. Thus, the information in the energy labels varies. Despite being mainly related to energy use, efficiency or energy cost, they can also refer to the consumption of other resources, such as water (e.g. washing machines), the emission of pollutants (e.g. NOx in space heaters) or the quality of the service provided, for instance the cleaning performance of laundry machines or comfort (e.g. noise levels of cooling products) (Calero et al., 2014).

Different types of energy labels are found around the world (Mahlia et al., 2002): endorsement labels, comparative labels and information-only labels (Fig. 3). Endorsement labels, such as those of the

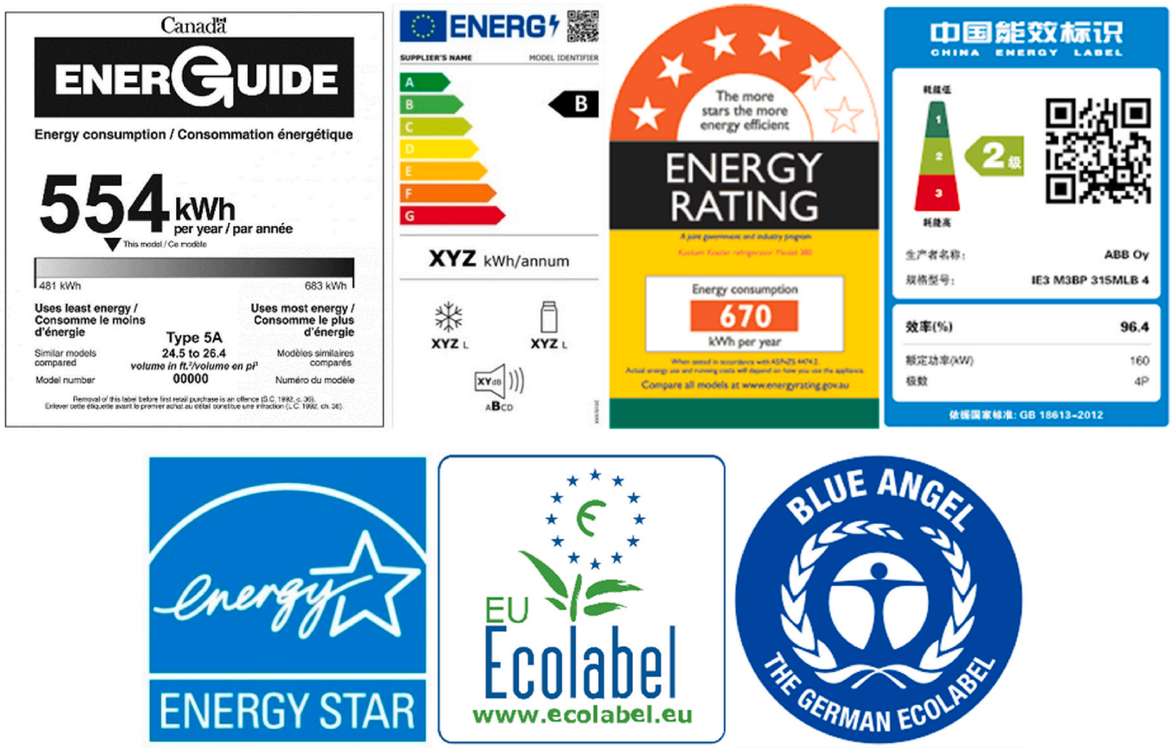


**Fig. 3.** Energy labels around the world. Comparative labels in the upper line: Canada, EU, Australia and China. Endorsement labels in the bottom line: US energy star, EU ecolabel, German blue angel.

US Energy Star program (Energy Star, 2022) or the EU Ecolabel (European Parliament and Council of the European Union, 2010a), consist of a logo or symbol indicating that specified criteria are met. In contrast, comparative labels rank products in the market by placing them along a continuous linear scale (in Canada) or within discrete categories of performance displayed as stars (in Australia (Holt et al., 2000)), letter grades (in Brazil (Huse et al., 2020) and in EU) or numbers (in China (Zhou et al., 2011)). Information-only labels just provide information on monetary or physical consumption (D'Adda et al., 2022). Furthermore, the labels can be mandatory, including enforcement or penalties for non-compliance (such as the Australian energy rating or the EU energy label), or voluntary, resulting from agreements between governments and manufacturers (such as the US energy star, EU ecolabel or the German blue angel).

Finally, regulatory instruments set minimum requirements to allow higher levels of penetration of efficient products by banning the sale of equipment that does not meet certain criteria. This relieves consumers of some of the responsibility for their purchasing decisions. Moreover, it promotes innovation, emphasising the importance of the product design stage (Sierra-Pérez et al., 2021), where 80–90% of products environmental impact is determined (Kengpol and Boonkanit, 2011).

Minimum requirements have been adopted in many countries over the last decades, proving to be easy to be implemented and effective for accelerating or triggering energy efficiency gains (Nadel, 2002). They were initially introduced in Europe, US, Japan and Taiwan in the 1970s and 1980s, but then spread to other countries such as Canada, Mexico, China, Malaysia, Korea, the Philippines, Singapore, New Zealand, Australia and Thailand. By 2022, more than 45 countries had voluntary or mandatory minimum energy efficiency standards in their legislation, according to the CLASP Policy Resource Centre (CPRC) database (CLASP, 2022). However, more work and support is needed to further extend them to the rest of the world to avoid that the inefficient and environmentally harmful products banned in other countries are simply dumped in unregulated markets, as in the case of Africa (Wagura and Carreño, 2019) and developing countries in Asia and South America.

The requirements can target the impact of either one or various phases of the product life cycle and they can be specific or generic. Specific requirements set numerical limits or thresholds on some specific technical aspects, such as energy efficiency, consumption of energy and/or other resources (e.g. water), emissions, noise, etc. In contrast, generic requirements establish non-quantitative obligations, such as information requirements or the compliance with other legislation or standards (e.g. recycling and reparability requirements).

The coexistence of different policy instruments should not be contradictory but complementary, as they target different sides of the market to address their failures. Fig. 4 shows the combined effect of labelling and minimum requirements in the market distribution and efficiency of refrigerators in EU, based on the results of a 1994 market survey (Bertoldi, 1994). Minimum requirements act on the right side of the curve by eliminating the least efficient models from the market, therefore improving the average efficiency of the products. Energy

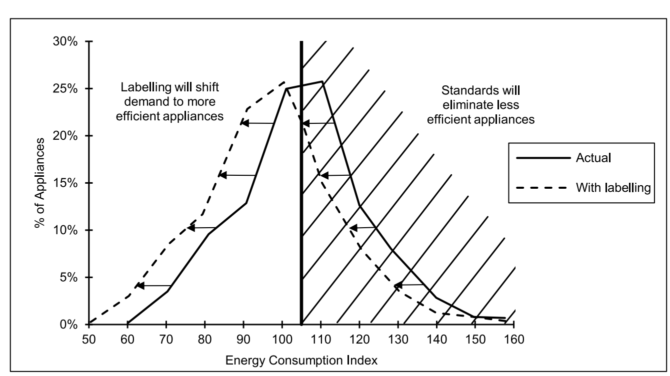


**Fig. 4.** Combination of measures: comparison of Energy Efficiency Indexes (EEI) *with and without labelling and requirements. Source:* Bertoldi (1994). Energy Efficiency Index (EEI) expressed as the percentage of annual energy consumption of a model against a reference.

labelling moves the curve leftwards towards better performing products, by allowing consumers informed decisions and stimulating manufacturers to design higher rated products (Mahlia, 2004). Under the implementation of such policies, Bertoldi (1994) estimated a 10% average efficiency improvement and the elimination of 50% of the domestic models on sale since the adoption of the first product policies, replaced by newly introduced, more efficient, models.

## 4. EU policies

In this section, the policy instruments at product level that have been used in the EU for the last 40 years are described: Energy Labelling, Minimum Energy Performance Standards, Ecodesign Directive as well as voluntary agreements, such as Ecolabels and Green Public Procurement. The introduction of these policy instruments is indicated in the timeline in Fig. 5. A common legislation at European level is important in this field, in order to adopt the same technical rules for all Member States and preserve the internal market and guarantee a fair competition (Bertoldi et al., 2006). Otherwise, political stringency could vary among countries, creating barriers to trade.

### *4.1. Energy labelling*

In EU, the first mandatory labelling program was adopted in 1979, when the 79/530/EEC Framework Directive (European Economic Community, 1979a) established the main objectives and rules for a categorical labelling scheme to classify household appliances using alphabetical rating scale ranging from A (most efficient) to G (least efficient). The details of the label of each type of equipment covered by the Directive would have been set out by independent Implementing Directives; however, only the Directive 79/531/EEC (European Economic Community, 1979b) addressing electric ovens followed this framework. They were both repealed by the 92/75/EEC Framework Directive (European Economic Community, 1992) for domestic appliances and the related implementing Directives for refrigerators and freezers (94/2/EC) (European Commission, 1994), washing machines (95/12/EC) (European Commission, 1995a), dishwashers (1999/9/EC) (European Commission, 1999), electric tumble driers (95/13/EC) (European Commission, 1995b), household lamps (98/11/EC) (European Commission, 1998), household electric oven (2002/40/EC) (European Commission, 2002b) and air conditioners (2002/31/EC) (European Commission, 2002c).

By that time, office equipment, such as computers, printers, monitors, etc., were kept out of the scope of the Energy Labelling Directive, due to its fast-changing technology and the difficulties to regulate its international market, with large part of the equipment manufactured outside European borders. However, the US Energy Star program (Energy Star, 2022), a voluntary labelling programme introduced by the US Environmental Protection Agency in 1992, already targeted this product group and was gradually recognised and adopted in many other countries, such as Canada, Japan, Taiwan, Australia and New Zealand, becoming de facto the international labelling scheme for office equipment. The Energy Star scheme was also adopted in EU from 2000 to 2018 as an official voluntary labelling program through an agreement that allowed the EC to have a role in managing the program and setting the minimum energy requirements of these labels (Bertoldi et al., 2006).

In 2010, the Energy Labelling Directive was again revised and repealed by the 2010/30/EU Framework Directive (European Parliament and Council of the European Union, 2010b) and the related implementing measures. Its scope was extended from household appliances to all Energy-related Products (ErP) with significant direct or indirect impact on energy consumption during their use phase, in order to bring additional energy savings and environmental gains, in concordance with the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan. Finally, it was updated in 2017 by the (EU) 2017/1369 Framework Directive (European Parliament and Council of the European Union, 2017), which maintained the general scope, but modified some provisions to improve its effectiveness, taking into account the energy efficiency technological progress achieved over recent years. The product groups covered by implementing measures within the Energy Labelling scheme are shown in Table 3 in the Supplementary Information, including the period they have been regulated, the framework directive under which they have been developed, as well as the repealed and amended regulations.

The effectivity of energy labels highly depends on how the relevant information is presented and how the program is promoted, as suggested by the successful results of a celebrity advertising campaign in Portugal (Boardman, 2004). The energy labels design have to be eye-catching, highlighting the energy efficiency class with a clear colour code from green (most efficient) to red (least efficient) to ease models comparisons. They need to be uniform and simple, so that consumers can easily understand them, but accurate, so they can be trusted and provide all the necessary information. They also should contain the energy efficiency indices and additional factors on which the categorisation of the products into the different classes is based (Russo et al., 2018). Moreover, a sound definition of the scale is essential to avoid its lack of sensitivity and credibility. Scale limits should be based on percentile analysis to ensure a correct distribution of the market between classes, while allowing for upgrading as a result of technological improvements, sometimes leaving the highest class empty at the beginning. In addition, there should be real differences between energy classes to avoid scepticism among consumers if products with better labels do not save more energy (Pérez-Lombard et al., 2009). Fig. 6 shows some examples of EU energy labels (electronic displays, dish washers, fridges and freezers, washing machines and washer driers and light sources), to show how the information contained can vary depending on the product group.

### *4.2. Minimum Energy Performance Standards (MEPS)*

Minimum Energy Performance Standards (MEPS) complement Energy Labelling policies by banning the sale of products that fail to meet specific minimum requirements. MEPS, addressing the energy efficiency, target the use phase (McMahon and Turiel, 1997), which is responsible for 75% of the product carbon emissions during the life cycle

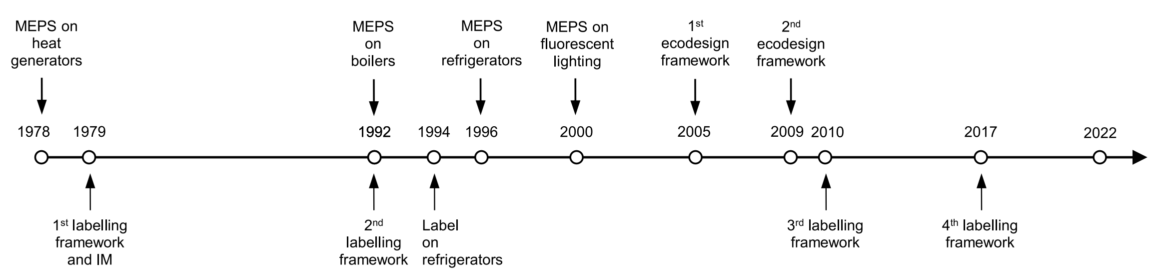


**Fig. 5.** Timeline of main product policies in the EU.

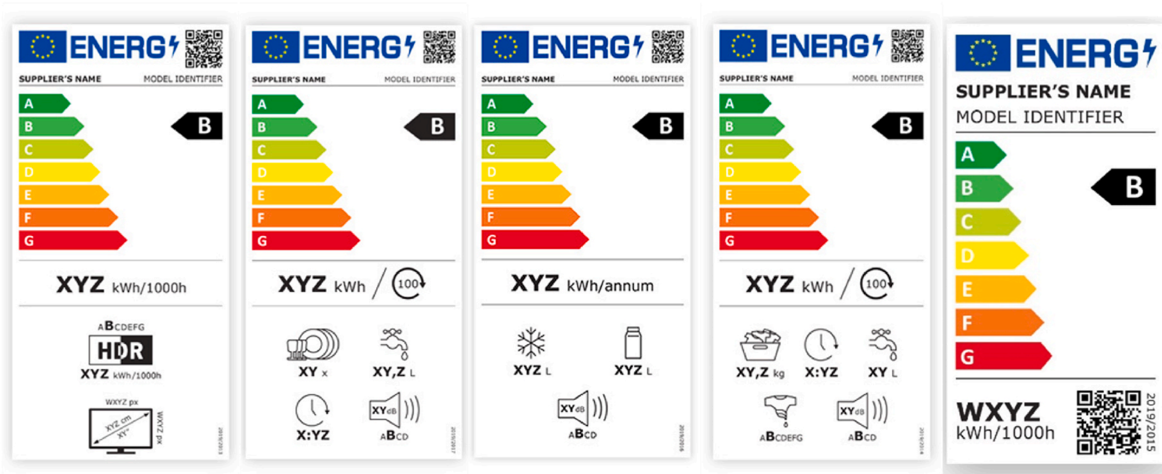


**Fig. 6.** Energy labels in EU for electronic displays, dish washers, fridges and freezers, washing machines and washer driers and light sources.

(Russo et al., 2018).

In Europe, MEPS were first adopted in the 1960s in Poland for a range of electrical appliances, and in France for cold appliances; however, almost all national legislations were repealed in the late 1970s and early 1980s, under the pressure to harmonise European trading conditions (Waide et al., 1997). At EU level, MEPS have only been adopted for water and space heaters in non-industrial buildings and heat and domestic hot water distribution (78/170/EEC) (European Economic Community, 1978), hot-water boilers fired with liquid or gaseous fuels (92/42/EEC) (European Economic Community, 2005), household electric refrigerators and freezers (96/57/EC) (European Commission, 1996) and for ballasts for fluorescent lighting (2000/55/EC) (European Parliament and Council of the European Union, 2000).

However, the lack of a framework directive that would facilitate the process of implementing measures and the strong opposition of manufacturers and some Member States to the MEPS directive on cold appliances (Menanteau, 2006), discouraged the EU from seeking additional legislation. Instead, manufacturers voluntary agreements were promoted and supported over the 1990s (Bertoldi and Rezessy, 2007), such as those covering washing machines, dishwashers, televisions, videocassette recorders (Nadel, 2002) and electric motors (De Almeida et al., 2008, 2017). Besides, the claim not to overlook life cycle stages other than the use phase led to the development of the Ecodesign Directive, which either repealed or amended MEPS related legislation.

### 4.3. Ecodesign Directive

The ecodesign approach aims at integrating environmental considerations in addition to the traditional business oriented ones into product development, in order to minimise the impact throughout its whole life cycle (Karlsson and Luttropp, 2006).

Over the last three decades, ecodesign methods and tools have been intensively developed, such as Life Cycle Assessment (LCA) or Life Cycle Costing (LCC), but their voluntary adoption by industry remained a challenge (Pigosso et al., 2015). Consequently, the EU has promoted its implementation through the Ecodesign Directive. In 2005, the Commission moved from independent product legislations (based on MEPS) to the Ecodesign Directive (2005/32/EC) (European Parliament and Council of the European Union, 2005) which established the first framework for setting ecodesign requirements for Energy-using Products (EuP). It was a milestone within the EU's Integrated Product Policy (IPP) (Council of the European Union, 2001), which aimed at reducing the environmental impact of products, ensuring that they are not simply transferred to other phases of their lifecycle (Hansen et al., 2005). As with MEPS regulations, non-compliant products were not allowed to be sold in the EU, thus eliminating the worst performing products from the market. This way, it addressed market failures and imperfections that prevented an optimal balance between consumption, production and environmental impact. The Ecodesign Directive was then the supply side instrument (suppliers) that provided a counterpart for the Energy Labelling Directive aiming at the demand side of the market (consumers).

However, this framework Directive covered only 31–36% of the environmental impact of the products considered for potential regulation (Labouze et al., 2003). Consequently, it was repealed by the 2009/125/EC Framework Directive (European Parliament, Council of the European Union, 2009) to expand the scope to Energy-related Products (ErP), to include any good that could have an impact on energy consumption during its use. This policy has been confirmed in 2020 to cover most of the products with the highest energy-saving potential, selected by sound and transparent methodologies in order to have maximum impact (European Court of Auditors, 2020).

The Ecodesign framework does not set product requirements, but defines the general rules and conditions for the Commission to do so through Implementing Measures or through voluntary agreements and other industry and associations self-regulation measures (Table 4, Supplementary Information). The process is strongly influenced by stakeholders,[4] that are involved through questionnaires, draft reports comments and meetings during the development of preparatory studies and through the discussion of the Working Paper in the Consultation Forum (Siderius and Nakagami, 2013). In the Consultation Forum, stakeholders can propose self-regulation measures provided that they (1) are open to participation, (2) add value beyond the business as usual, (3) cover at least 80% of units placed on the market (European Commission, 2016), (4) set quantified and staged requirements, (5) are publicised to ensure transparency, (6) have a defined monitoring and reporting system, (7) are cost-effective, (8) sustainable and (9) consistent with other policies (Bundgaard et al., 2017). The Commission can either accept or reject them based on their corresponding impact assessments, but the framework directive sets them as a priority, as they are likely to achieve the policy objectives faster and less costly than mandatory requirements (Papadoyannakis, 2006). However, voluntary Ecodesign agreements have only been adopted for few product groups due to the demanding criteria and the stringent procedure that

[4] Stakeholders included are trade and business associations (manufacturers, traders, retailers, and importers), professional associations, NGO's, academia, research institutes and think tanks, environmental protection groups, consumer organisations, etc.https://ec.europa.eu/transparency/expert-groups-register/screen/expert-groups/consult?do=groupDetail.groupDetail&groupID=3609.

stakeholders must undertake for their development: complex set-top boxes (COM(2012) 684) (European Commission, 2012) imaging equipment (COM(2013) 23) (European Commission, 2013a) and game consoles (COM(2015) 178) (European Commission, 2015a). Moreover, an analysis of the existing voluntary agreements highlighted them as unambitious (Pollex, 2021), thus reducing their potential benefits.

Ecodesign requirements can be specific or generic. Specific requirements include minimums for energy efficiencies (e.g. ratio between useful energy by energy required for its generation [%] for boilers) or performance (e.g. dishwashers cleaning performance or lamps life time [h]), and maximums for energy use (e.g. in simple set-top boxes, [W]), water consumption (e.g. in washing machines [L/cycle]), sound levels (e.g. in air conditioners [dB(A)]), chemical emissions (e.g. NOx in boilers [mg/kWh]) or component contents (e.g. mercury in lamps [mg]). In contrast, generic requirements involve mandatory information requirements on maintenance, waste disposal, separation and recycling or hazardous substances contents, and compliance with harmonised standards, such as plastic marking to facilitate the reuse and recycling.

The methodology to define minimum requirements under the Ecodesign Directive has been greatly refined compared to that of the previous MEPS directives. First, the best available technology and the legislation already set in countries inside and outside the EU are considered. Furthermore, a techno-economic-environmental assessment at product level is conducted to define requirements and their level of stringency following the Methodology for Ecodesign of Energy-related Products (MEErP) (Kemna, 2011). MEErP identifies options based in the least life cycle costs (LLCC), and is supported by a ErP 'EcoReport Tool' that translates product characteristics into environmental impact indicators according to the LCA approach (Cellura et al., 2014). Hence, it enables the selection of resources and technological solutions that minimise the impacts throughout the life cycle (Dahmani et al., 2022).

The MEErP was evaluated and considered to fit for purpose in the decision-making process of the Ecodesign and Energy Labelling legislative framework in 2013, and it is currently under revision to ensure that it continues in line with the policy developments of the last years (Gama et al., 2021). The main limitations identified of the methodology have been:

- The need for the update of the environmental impact data contained in the EcoReport tool, as well as an evaluation of the relevance of the input categories with regard to material efficiency.
- The relevance for a more systematic inclusion of material efficiency and of environmental footprint aspects in the design options and in the construction of the LLCC curve.
- The relevance of a more systematic inclusion of societal life cycle costs.
- The need for a more refined method for the evaluation of the economic impacts.

The product requirements are usually introduced gradually in different tiers, to mitigate the negative impacts they might have on industry and to allow time to improve, adapt and develop new products, especially for local and small manufacturers (Mahlia et al., 2002). In addition, they need to be periodically reviewed, according to the dates defined in the implementing measures and updated if there is potential for improvement.

### 4.4. Other policy instruments on products

Other policy instruments for the promotion of energy efficient products at EU level are: the EU Ecolabel, the Green Public Procurement (GPP) and the Energy Performance of Buildings Directive (EPBD).

The European Ecolabel, established in 1992, is the official EU voluntary label for environmental excellence. It certifies products and processes with low environmental impact throughout their entire life cycle (European Parliament and Council of the European Union, 2010a). Products are awarded with this label by third parties provided that they meet high environmental standards developed, published and promoted by the European Union Ecolabelling Board (EUEB). Ecolabel products cover electronic devices, lubricants and detergents, but also

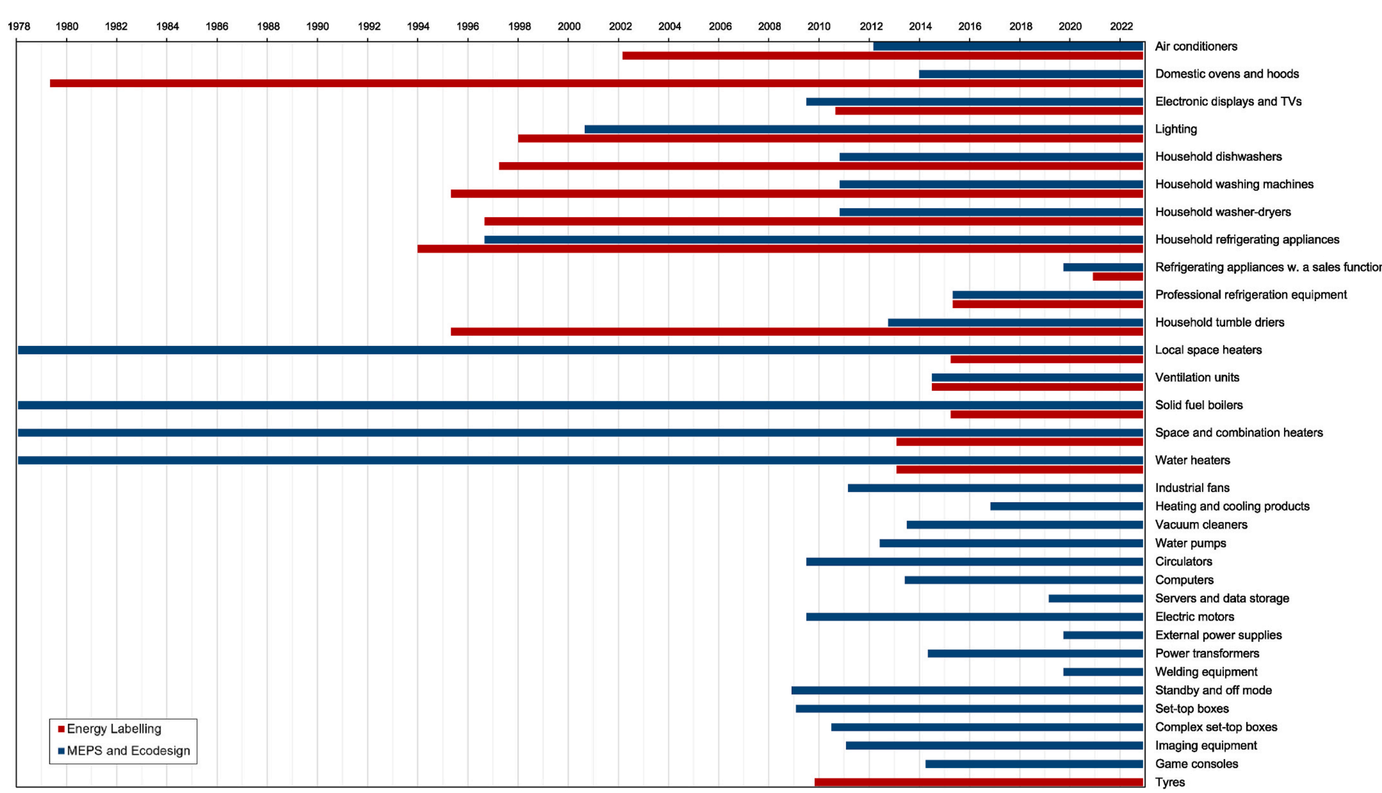


**Fig. 7.** Timeline of product policies in EU: Energy Labelling (red) and requirements (MEPS and Ecodesign) (blue).

non-Energy-related products and services, such as textile, furniture, etc. Thus, it does not contradict the Energy Labelling scheme, but complements it.

The Green Public Procurement (GPP) is a voluntary instrument that guides public authorities to purchase goods, services and works with reduced environmental impact throughout their whole life cycle, based on LCA and LCC techniques (European Union, 2016). Minimum GPP criteria are developed under the 2014 Procurement Directives (2014/24/EU (European Parliament and Council of the European Union, 2014a) and 2014/25/EU (European Parliament and Council of the European Union, 2014b)) for product groups such as computers, monitors, tablets and smartphones, data centres and imaging equipment. Due to the large volume of public spending in goods, services and works (equivalent to 19% of the EU's gross domestic product (European Parliament and Council of the European Union, 2012)), this policy tool can drive market transformation and behavioural changes on citizens and enterprises by leading by example. Furthermore, the Energy Efficiency Directive (2012/27/EU) (European Parliament and Council of the European Union, 2012), in its Art.6, defines additional measures to be taken by central government authorities and voluntarily by other public authorities, limiting the purchasing choice to those products belonging to the highest energy efficiency class of the Energy Labelling or, if not covered, that comply with the benchmarks of best available technologies specified in their corresponding implementing measures of the Ecodesign Directive.

The Energy Performance of Buildings Directive (EPBD) (European Parliament and Council of the European Union 2010b) is the key piece of legislation to improve the energy efficiency of buildings. While product policies define low-level requirements, the EPBD allows for the trade-off of components prescriptions and sets minimum energy requirements and certification schemes at building level. It is therefore necessary to develop strong links between these regulations to avoid inconsistencies. In this sense, the introduction of product package labels (e.g. Regulation 811/2013 on space heater or combination heater + temperature control + solar device (European Commission, 2013b)), has been an attempt to rate building technical systems based on the extended product approach. This would prevent efficient components leading to inefficient systems, as the optimisation of the entire application has a greater influence on the overall energy efficiency than the rated efficiency value of the individual components (Weis et al., 2019). However, these labels resulted to be quite complex and difficult to understand by the end-users. With the revision of the EPBD, more synergies would be needed between the minimum requirements for buildings and those developed in the Ecodesign framework, with the aim of achieving an Energy Building Code that encompasses both.

## 5. Discussion

Although the introduction of product policies in the EU started already in the late 1970s, mandatory specific implementing measures were almost non-existent until the 1990s, when the spread of the first energy labels began (Fig. 7). Despite the MEPS directive on heat generators already came into force in 1978, the decision on the minimum requirements was left to Member States, so that common European thresholds were only introduced from 1992 onwards. The initially weak requirements for individual devices have gradually been transformed into a coherent set of implementing measures under harmonising framework directives, although they became sufficiently comprehensive only around 2010. Thus, despite the EU's 40 years of experience in product policies, considerable progress in terms of scale and ambition has only been made in the last 10 years, as demonstrated by the extension of their scope to all energy-related products and to the different stages of their life cycle.

This section focuses on the discussion on the implementation of the two main product policies at EU level, the Ecodesign and Energy Labelling Directives, as the mandatory instruments currently in force.

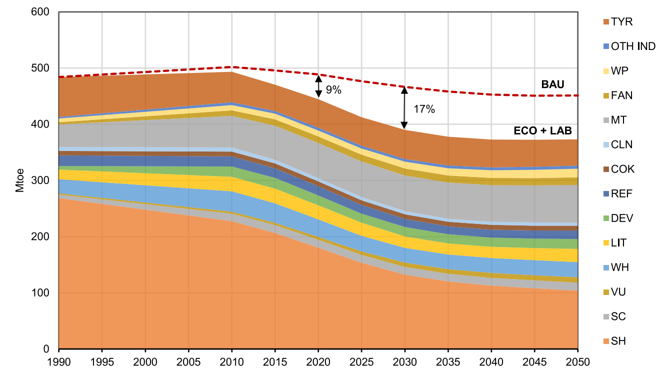


**Fig. 8.** Savings in final energy consumption of Energy-related Products covered by Ecodesign and Energy Labelling policies: space heating (SH), space cooling (SC), ventilation (VU), water heating (WH), lighting including stand-by (LIT), electronic devices (DEV), refrigerators and freezers (REF), cooking appliances (COK) and cleaning appliances (washing machines, driers, dish washers, vacuums) (CLN) in Buildings; electric motors (MT), fans (FAN), water pumps (WP), Standard Air Compressors and Welding Equipment (OTH IND) in Industry; and tyres (TYR) in Transport. Source: EIA (European Union, 2021).

Fig. 8 shows the impact of such policies since 1990, comparing the historical and ongoing trends of final energy consumption (ECO + LAB) with the business-as-usual scenario (BAU), which represents the baseline without measures. In 2020, the products covered by these measures consumed 50% of the EU total final energy, leading to 46 Mtoe energy savings according to the annual Ecodesign Impact Accounting report (European Union, 2021). The main contributions to savings came from Heating.

Ventilation and Air Conditioning (HVAC) systems, lighting and cold appliances, as they were among the first product groups targeted by Ecodesign and Energy labelling measures. Incandescent lamps in households have been gradually replaced by efficient LED bulbs, favoured by the reduction of the price of the new technologies, decreasing the consumption of an average bulb to one fifth; while refrigerators have reduced the energy consumption of an average model from 477 kWh/a to 181 kWh/a in the last 30 years. By 2030, additional savings are expected to reduce the final consumption by 17%, compared to the BAU.

The results of these policies are also reflected in user expenditure. On the one hand, the stringent requirements could rise the manufacturing costs and consequently prices of the products in the market. However, this effect is limited to some extent by technological innovation, which reduces the cost of efficiency, and by market changes, which contribute to lower markups and economies of scale in the production of more efficient units (Dale et al., 2009). On the other hand, energy savings as the result of the implementation of the policies compensates the rising energy cost and reduces energy bills. According to the annual Ecodesign Impact Accounting report (European Union, 2021), Ecodesign and Energy Labelling Directives led to savings of 60 G€ in user expenditure, as the balance of 23 G€ additional acquisition costs (for better products) and 82 G€ savings on costs for energy and consumables (e.g. 1507 million $m^3$ drinking water and 0.2 Mt printer paper saving). By 2030 the total expense savings are expected to increase up to 116 G€.

Nevertheless, several limitations and open issues have hindered the full success of product policies, either affecting Energy labelling, Ecodesign, or both. Their discussion aims to shed light into future progress to further increase their positive impact.

### 5.1. *Key challenges for energy labelling and Ecodesign Directives*

#### 5.1.1. *Compliance and enforcement*

The compliance with Ecodesign and Energy labelling prescriptions is auto-certified by product's suppliers, who obtain a CE marking and an energy class for their products by providing a declaration of conformity with the applicable legislation under their sole responsibility. However, an EU Special Report, which audited both directives in 2020, concluded that the effectiveness of the policies was significantly reduced by the high rate of non-compliance by manufacturers and retailers (European Court of Auditors, 2020). The EC estimated that 10–25% of products sold on the market in 2019 were non-compliant, decreasing potential energy savings by 10% (European Commission, 2019a). For refrigerators, Goeschl (2019) estimated that self-certified Energy Efficiency Indexes underreported energy consumption by 13%.

It is Member States responsibility to carry out an effective market surveillance to enforce the compliance with product legislation to ensure that consumers benefit from accurate energy labels and that ecodesign requirements are correctly implemented (European Parliament and Council of the European Union, 2008). Each Member State must designate a Market Surveillance Authority (MSA) and provide it with sufficient power and resources to perform appropriate checks on an adequate scale. Inspections can be visual, to see if the label is displayed; documentary, to see if the product information sheet contains the appropriate references to the regulation and the technical information required; or through laboratory tests, to verify the declared performance. Moreover, MSAs should detect the manipulation of test results of those products which are able to automatically recognise test conditions and alter and improve their performance (circumvention) (Stamminger et al., 2019). Non-compliant products must be withdrawn from the market by the MSAs and manufacturers must be penalised.

Given the low level of market surveillance activity in most Member States (European Commission, 2015b), the EC has funded projects to promote inspections and compliance tests. Moreover, it operates two product databases to disseminate information and facilitate cooperation between MSAs. The Information and Communication System on Market Surveillance (ICSMS)[5] includes the results of compliance checks performed by Member States and provisional measures adopted so that other MSA can use them and avoid duplication of work. The European Product Registry for Energy Labelling (EPREL)[6] provides technical information of products both for consumers to make informed choices and for the Commission to carry out up-to-date inspections (Berwald et al., 2019).

To reduce the high non-compliance rate, an alternative enforcement system could be proposed, despite its higher cost, in terms of needed resources and time. The CE marking and the energy label could cease to be auto-certified by the suppliers to be certified only by third parties to avoid biased results. Thus, the procedure would follow the following sequence: (1) construction of indicators constituting the thresholds or category ranges; (2) definition of standard test procedures for their assessment; (3) certification of performance by an independent organization or laboratory; and (4) application of the policy by banning and labelling products (Pérez-Lombard et al., 2011).

#### 5.1.2. Gap between real and measured consumption

Products energy consumption is strongly influenced by their operating conditions and on users' behaviours (Geppert and Stamminger, 2013; Hueppe et al., 2021). For instance, the consumption of HVAC systems is highly dependent on the outdoor temperature, dishwashers could consume 6–73% more energy when used with different programmes and refrigerators consumed up to 47% more energy, considering different door opening patterns (CLASP et al., 2017). The methods for calculating the energy performance of the legislated products should reflect normal conditions of use so as not to mislead consumers. It was in fact the case for the Energy Labelling for vacuum cleaners ((EU) 665/2013 (European Commission, 2013c)), which was annulled by the General Court in 2018, in response to Dyson's argument of not providing for testing with the dust receptacle loaded (Lappalainen, 2023).

Thus, it is fundamental to define in detail the standard test conditions for the measurement of the key parameters that establish the ecodesign thresholds and the Energy Label classes. Otherwise, this may also lead to the incorrect comparison and ranking of the models and the unequal ban on the sale of products. Sound harmonised standards for test procedures are needed to make consistent evaluations by providing agreed definitions of technological concepts and measurement methods and conditions (European Court of Auditors, 2020). They must represent realistic product usage patterns (Stawreberg and Wikström, 2011) and measurements that are reliable and repeatable at a reasonable cost (Meier and Hill, 1997; Spiliotopoulos et al., 2019). Three European Standard Organisations (ESO) are in charge of developing harmonised test protocols for EU legislation: the European Committee for Standardization (CEN), which focuses on general and mechanical matters; the European Committee for Electrotechnical Standardization (CENELEC), which focuses on electrotechnical matters; and the European Telecommunications Standards Institute (ETSI), which produces standards on telecommunications (Hughes, 2017). They develop test protocols in close liaison with international standards agencies, the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC), often modifying or adopting test procedures they previously established (Turiel, 1997). In absence of harmonised standards, the Commission publishes transitional measurement and calculation methods, valid for a specific product group, in the Official Journal of the European Union that the suppliers need to follow until the official harmonised standards are developed.

Nevertheless, some variations in the measurements can emerge during verification tests due to differences in the equipment used by suppliers and surveillance authorities. Thus, verification tolerances are allowed and defined in the implementing measures, which have sometimes been misused by manufacturers and importers to report better performance of their products and achieve a better classification. For instance, since the ISO test procedure for refrigerators set a $\pm$15% tolerance, while energy categories comprised about 10% of the efficiency range, manufacturers exploited the tolerance limit in the early years of the labelling scheme and sometimes claimed a C refrigerator to be an A (Winward et al., 1998). In order to avoid abusive practices, the regulation (EU) 2017/254 (European Commission, 2017a) was published to underline the sole purpose of tolerances for verifying compliance. Besides, energy labelling categories should be well defined with this in mind, covering a sufficiently wide range so that products do not change class as a matter of protocols' tolerances.

The dependence of products energy consumption on operating conditions may also lead to the inaccurate estimation of savings and efficiency improvements that distort the accomplishment of the policy goals. The EU is therefore working on the development of methods that capture real energy consumption by end-uses based on in-situ measurements or a combination of metered data and engineering models, in order to improve the evaluation of the impact accounting model (Castellazzi et al., 2023).

#### 5.1.3. Too long regulatory process

The regulatory process for the definition and adoption of implementing measures under both the Ecodesign and the Labelling Directives are long, due to the technical complexity and the several rounds of interactions with stakeholders (Maitre-Ekern and Dalhammar, 2016). First, the EC develops Working Plans which select and prioritise the products that will be investigated for their suitability as targets for legislation (Malcolm, 2011). Then, preparatory studies are conducted by consultants, identifying requirements and their level of stringency. The result is a Working Paper containing recommendations as baseline information for the following steps (Bundgaard et al., 2015). Finally, an impact assessment is made to study the potential savings and costs of different options, to conclude with specific objectives and the draft of an implementing measure. Before being adopted by the EC and published in

5 https://webgate.ec.europa.eu/icsms/.
6 https://eprel.ec.europa.eu/screen/home.

the Official Journal, the implementing measures also need to go through an internal review process, the approval of the national experts in the Regulatory Committee and the scrutiny by the Council and the European Parliament (Polverini and Tosoratti, 2017).

Despite the process is designed to theoretically last up to three years and a half, the actual process starting with the preparatory study has often been about twice as long. Some delays could have been avoided, for example regarding the adoption of measures in the form of packages which, while helping to communicate the impact of multiple product groups to better demonstrate meaningful policy outcomes, prevents the adoption of the measures that are ready until the full package is completed (European Court of Auditors, 2020). The length of the regulatory process is key for the success of the policy, as Ecodesign requirements and the categories of the energy labels can become outdated due to technological progress. In addition, delays mean that time is lost to exploit the significant potential for energy savings and reduce environmental impacts (APPLiA et al., 2018; Zygierewicz, 2017).

#### 5.1.4. Unambitious targets

For compliance with the 2009/125/EC Ecodesign Framework Directive (article 21), the EC carried out an evaluation of the effectiveness of the Directive and of its Implementing Measures in 2012 (CSES et al., 2012). It criticised the lack of ambition of the objectives for some product groups, such as televisions, refrigerators or dishwashers, which were quickly left behind due to the technological development and delays in the regulatory process (Schiellerup, 2002). Some of the requirements were already fulfilled and the majority of the products were already concentrated in the most efficient categories before they came into force. Thus, the regular review of the requirements foreseen by the product regulations is crucial to avoid this issue and improve their effectiveness (Hinchliffe and Akkerman, 2017).

Furthermore, the directives only apply to new products entering the market, thus excluding second-hand sales and available stocks. Hence, their effect will be quite limited until they reach a wider product coverage in the market. Consequently, the impact of the measures already in force is estimated to rise about 50% by 2030.

### 5.2. Additional shortcomings of energy labelling

#### 5.2.1. Confusing energy labels

Over the years of implementation, the technological progress often led to the accumulation of most models of a given product group among the most efficient categories, clustering a too wide range of alternatives in the A-class and leaving some of the lower categories empty. This prevented consumers from differentiating between the best options and discouraged manufacturers from further improving their products. As a result, the recast Framework Directive 2010/30/EU (European Parliament and Council of the European Union, 2010b) introduced additional classes (A+, A++ and A+++) above the existing scale and repealed the lowest (E, F, G) to maintain a 7-grade scale. However, it was only adopted for those product groups where it was really necessary, such as refrigerators (Bjerregaard and Møller, 2019). This led to the coexistence of both scales and was misleading for consumers, who believed that there were better energy classes when looking across the products that remained in the A-G scale. Moreover, it weakened the market transformation as incremental savings between A+/A++/A+++ were perceived to be less important and motivating than those between C/B/A classes (Waide et al., 2013).

To address this issue, the EC took steps to improve energy labels and the Framework Directive (EU) 2017/1369 (European Parliament and Council of the European Union, 2017) called for the rescaling of product labels back to A-G to improve transparency and homogeneity, with successful results as demonstrated by Faure et al. (2021) for German refrigerators purchases. However, in absence of the revision of certain implementing measures under this framework, there are still appliances using the A+++ to D labels, such as tumble dryers or cooking appliances. Also, there is still confusion between new and previous scale, as shown in a Polish survey (Stasiuk and Maison, 2022); for these reason, educational and information campaigns for end-users to better understand energy labels could be worthwhile and useful, along with preliminary consumer studies when developing new energy labels, to check that the pictograms and the label as a whole are intelligible.

Another misleading factor is the fact that the highest energy classes do not always lead to reduced consumption since they are sometimes based on relative values (e.g. kWh/L for cold appliances or kWh/kg for washing machines), favouring large appliances (Boyano et al., 2020). This could encourage manufacturers to produce bigger equipment to improve their energy label, so that better labels could mean large capacity (and, thus, higher efficiency, as the ratio of service output to energy input) rather than low energy consumption (Michel et al., 2015; Schmitz et al., 2016). Therefore, labels should consider also the energy consumption and not only the efficiency in order to capture the potential of technology improvements for energy savings (Siderius et al., 2012).

Moreover, energy labels have been sometimes shown to lack clarity. For instance, a consumer study in 2016 found that less than one third of the respondents could understand all the information provided on the heaters energy label (Dünnhoff, 2016). To solve this issue, the Commission reviews potential weaknesses in the understanding of the labels and conducts specific consumer testing when developing product-specific energy labels to confirm their comprehension (European Commission, 2015b). As a result, the response to energy labels is quite extensive and recent consumer surveys have showed that about 85% of EU citizens consider energy labels when making a purchasing choice (European Commission, 2017b). Surveys also showed that 80% of the consumers knew what they stand for (European Commission, 2019b) and correctly understood the scale (Alborzi et al., 2017; IPSOS and London Economics, 2014).

#### 5.2.2. Split incentives

On the consumer side, there are also barriers that limit their response to energy labelling, such as the split incentives described in section 1. Consumers who will not be responsible of paying energy bills are more likely to buy products in less efficient categories or do not even pay attention to energy labels. Thus, additional efficiency measures for such cases need to be implemented, such as setting minimum efficiency requirements for products that enter the market.

#### 5.2.3. Choice determinants

Finally, there are many other determinants influencing the purchasing decisions that may divert energy and monetary aspects from being the main selection criteria, such as the lack of environmental awareness, the limited range of models available at the point of sale, the quality of the service or design factors related to the space and layout and fashion and aesthetic considerations (Boardman, 2004). For instance, electronics choices prioritise the screen size and resolution or the processor speed (Kelly, 2012).

### 5.3. Other constraints of the Ecodesign Directive

#### 5.3.1. Lack of life cycle perspective

Ecodesign definition implies expanding the boundaries of the engineering problem to evaluate stages of the product life cycle others than use phase, such as manufacturing, distribution, and end of life (Thakker and Bakshi, 2022). Thus, it is closely related to the Circular Economy concept, which represents a change from the traditional linear model (take - make - use - dispose) to another in which waste is returned to the process and closes the loop (Bodova, 2017). The move towards Circular Economy is spreading more and more in industry (Spreafico, 2022) and fully supported by the EC as a vital pathway to improve resource efficiency (Mendoza et al., 2017). In this line, the Ecodesign Directive has been identified as one of the key legislative tools for its implementation (Marrucci et al., 2019) as the framework already makes legally possible to transform Circular Economy principles into requirements at product level, for instance considering resource consumption, reparability, durability and recyclability (Alfieri and Bernad Beltrán, 2023), as expressed in Annex I of the directive.

However, the implementation measures under Ecodesign Directive have focused primarily on energy consumption during the use phase (Huulgaard and Remmen, 2012). The lack of requirements with a fuller life cycle scope was due to the minor involvement of DG Environment in the development of the implementing measures (mainly addressed by DG Energy and DG Enterprise), and to the absence of harmonised standards to deal with resource efficiency (Dalhammar, 2016). As a response, the EC issued the standardization mandate M/543 for ecodesign standards to support test protocols (Patra, 2021), as those to assess the durability of energy-related products (CEN, 2020a), their ability to be remanufactured, repaired, reused and upgraded (CEN, 2020b, 2020c), their recyclability and recoverability (CEN, 2020d) or the proportion of reused and recycled components (CEN, 2020e, 2019).

In 2019, novel and binding circular economy requirements were first integrated in the Regulation (EU) 2019/424 (European Commission, 2019c) on the Ecodesign of Enterprise Servers (Mathieux et al., 2020). It has then been followed by other Ecodesign Regulations, as those on electronic displays, refrigerators, dishwashers, washing machines and washer driers and welding equipment. However, clearer guidelines on the use of the standards should be established as their actual use shows significant variance in how they are applied, potentially hindering continuity in the development of standardization (Bundgaard and Huulgaard, 2023).

Circular Economy requirements need to be further considered in the next implementing measures and amendments, in parallel with the strengthening of other life cycle-related product policies Table 2. To better integrate them in the EU policy, the Commission proposed in 2022 a regulation establishing a framework for Ecodesign for Sustainable Products Regulation (ESPR) to repeal the Ecodesign Directive and cover non Energy-related Products and improve the focus on circularity (European Commission, 2022). However, the extension of the scope to a broader life cycle perspective should be carefully addressed, ensuring the correct balance between the use phase requirements and those of the rest of the stages.

#### 5.3.2. Over-focus on buildings

The selection criteria for a product group to be covered by an implementing measure is based on its environmental impact, its potential for technological improvements and energy savings without entailing excessive costs, and its volume of sales and trade (more than 200 thousand units a year). This last criterion is mainly met for devices used in buildings, especially households. This is why, despite Ecodesign is intended to cover cross-cutting technologies in all the consuming sectors, indeed, it mostly regulates equipment used in the building sector. Thus, the priority should be to achieve greater coverage in transport but mainly in industry, keeping the focus on products with the highest energy efficiency potential, in line with the EU's decision not to regulate small household appliances, e.g. toasters and hairdryers in 2016. Nevertheless, the impact of the buildings sector should not be overlooked since it indeed contributed to 40% of final energy consumption and one third of $CO_2$ emissions in the EU in 2019 (Odyssee, 2021).

**Table 2**
Other life cycle-related product policies beyond Ecodesign Directive.

| Directive | Scope |
|---|---|
| WEEE Directive (2002/96/EC) | Management of waste of electrical and electronic equipment. |
| RoHS Directive (2002/95/EC) | Presence of certain hazardous substances in products, including energy related products. |
| REACH Regulation | Registration, authorisation and evaluation of chemicals. |
| F-Gas Regulation (842/2006) | Use and marketing of fluorinated greenhouse gases and measures for controlling leakages. |

## 6. Conclusions

As part of its strategy to curb climate change, the EU has placed efficiency at the forefront of their energy policies. It could also play a decisive role in solving the current energy crisis by reducing the consumption, and thus the EU reliance on Russian natural gas, with no detriment to the welfare of consumers. Focusing on the efficiency of products is essential due to their large potential for energy savings, as they represent almost three quarters of the primary energy supply. In addition to their benefits to the environment and energy security, improvements in products efficiency increase companies' competitiveness and result in consumers' monetary savings, which could reduce energy poverty and improve living standards.

Although EU product policies were first adopted in the late 70s, their scale and ambition only increased in the 1990s after years of poor and weak implementation. In 2020, the mandatory policy instruments covered half of final energy consumption: the Energy Labelling, targeting the demand side of the market (consumers) and the Ecodesign Directive, addressing the supply side (manufacturers and importers).

In the EU, energy labelling is a classification of products using an alphabetical rating scale, helping consumers to make informed purchases and moving the market to more efficiency choices. At the same time, Ecodesign Directive sets minimum requirements to eliminate least efficient products by banning the sale of those that do not meet certain criteria. Their combined effect already resulted in 9% of energy saving in 2020, and they are expected to further reduce the final energy consumption by 17% in 2030, compared to the business-as-usual. Among many, successful examples of their impact are the replacement of inefficient incandescent lamps in households with LED bulbs which consume less than one fifth, and the reduction of the consumption of an average new refrigerator from 477 kWh/a to 181 kWh/a in the last 30 years.

However, there are still many limitations and open issues that need to be addressed to increase effectiveness of the EU efficiency in product policy implementation. First, the role of Member States on market surveillance must be improved to reduce the high non-compliance rates (10–25%) by being adequately funded. Both, the ICSMS and the EPREL databases should be exploited to disseminate information and facilitate cooperation between Market Surveillance Authorities to avoid duplication of work and increase the enforcement. Second, the harmonised standards for test procedures should be clearly defined before the entry into force of the products measures to ensure consistent evaluations, the correct ranking of the models and the fair ban on the sale of products. Third, the regulatory process should be accelerated to avoid outdated and unambitious requirements and the loss of time to exploit energy savings. Fourth, the non-compliant stock should be withdrawn from the market within 3 years after the entry into force of the policies, in order to increase their effect while allowing the industry to adapt and mitigate their negative impacts. Fifth, the response of consumers to energy labels should be periodically revised to identify and solve barriers, such as the misleading categories or the misunderstandings between energy savings and energy efficiency. Sixth, requirements should be frequently revised to adapt them to the technological progress and they should expand their scope to the whole life cycle, keeping the balance between the use phase and the rest of the stages. Finally, despite products policies already cover 82% of the energy consumption in the buildings sector, there are still other relevant equipment that could be regulated, especially in other sectors where products not yet covered by EU policies offer great potential for energy savings.

To further reduce energy consumption in the EU, priority should be given to energy performance when balancing trade-offs between energy efficiency and material efficiency requirements in new product policies, to keep in line with decarbonisation objectives. Moreover, product policies should be coupled with additional measures, such as incentives and investments to support technological innovation and consumers' acceptance, as well as with the energy renovation of the building stock as indicated in the EU Renovation Wave. Finally the promotion of more energy conservation behaviours among citizens is also of key importance. The concept of energy sufficiency should also be considered in energy efficiency policy making, for example by introducing progressive standards (Bertoldi, 2022). Moreover, product policies should be accompanied and aligned with other EU regulation and directives targeting different aspects of the demand and supply sides of the energy system, so as to enhance their joint effect. In this respect, the synergies of product policies with other existing directives, such as the Energy Efficiency Directive (EED), the Energy Performance of Buildings Directive (EPBD), the Renewable Energy Directive and the Electricity Market Directive, allowing appliances to be smart and interact with the energy grid, could be subject of future investigation. In addition, statistical and econometric analyses (Bertoldi and Mosconi, 2020; Aydin and Brounen, 2019) could be applied to unravel the reasons for the energy savings over the last 40 years to better understand past experience due to the EU product policies and thus refine current policies to maximise their outcome.

With all, the progress of OECD countries in product policies to reduce the environmental impact will be futile if banned inefficient products are simply exported to developing countries. To achieve meaningful results, it is necessary to prevent dumping by implementing standards and labelling policies in the countries where this legislation is non-existent or weak. Options for global convergence and collaboration based on the positive outcomes of successful initiatives should be further explored. In this sense, this review aims to provide a roadmap in this field by illustrating the evolution of the product policies in the EU whose success encourages their replicability in other regions and countries.

## Disclaimer

The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

## Declaration of competing interest

I the author confirm that no authors has any conflict of interest of any possible nature. In addition, the authors do not have *any financial and personal relationships with other people or organisations that could inappropriately influence or bias their work*.

I the author confirm also that the submitted manuscript has not been published previously, that it is not under consideration for publication elsewhere, that its publication is approved by all authors and explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form.

## Data availability

No data was used for the research described in the article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2023.138442.

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