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THE FUTURE OF ECOLABELS

Improving material efficiency in the life cycle of products: a review of EU Ecolabel criteria

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Abstract

Purpose Material efficiency encompasses a range of strategies that support a reduction of material consumption and waste production from a product's life cycle perspective and which can help the transition towards a circular economy. The aim of this paper is to analyse the state of implementation of material efficiency requirements for products as set out in existing EU Ecolabel criteria, consider possible improvements, identify current limitations and describe potential or existing synergies with other EU policies and initiatives.

Methods Key concepts related to material efficiency have been provided and classified into three groups which are, in order of decreasing priority: reduction, reuse, and recycling/recovery. This classification system has then been used for the analysis of existing requirements set out for different EU Ecolabel products. This includes a description of potential environmental benefits, trade-offs, market barriers and risks. Material efficiency concepts have then been cross-checked with other EU policies and initiatives.

Results and discussion Looking at EU Ecolabel criteria for 26 different product groups revealed a broad range of material efficiency aspects, some of which are influenced by the nature of the product group itself. Some material efficiency aspects were broadly integrated into EU Ecolabel criteria through complementary strategies (e.g. design for durability, recyclability, availability of spare parts, reversible disassembly and provision of information). However, ways to implement additional material efficiency requirements (e.g. minimum lifetime of products) should be sought further. A symbiotic relationship can exist between the EU Ecolabel and many policy tools in the sense that regulatory and standardisation frameworks can offer a robust basis for justifying the integration of material efficiency aspects in the EU Ecolabel, while the EU Ecolabel can explore and promote approaches targeted at front runners in material efficiency aspects in a voluntary manner.

Conclusions The experience gained from implementing material efficiency aspects in the EU Ecolabel could serve as a reference for shaping design, communication or policy initiatives aimed at the promotion of a more circular economy. Attempts to quantify the impacts from material efficiency measures should be also integrated systematically in future research, with the support of tools like life cycle assessment. However, additional considerations of political, technical and socio-economic nature must be considered when assessing the relevance, feasibility and ambition level of any material efficiency–related requirements.

Keywords Circular economy · EU Ecolabel · Life cycle · Material efficiency · Product policy · Requirements

1 Introduction

The intention of the European Commission (EC) to transform Europe's economy into a more sustainable one is reflected through its environmental policy. Already twenty years ago, the EC recognised the need to develop product-focused environmental policy (Ernst and Young 1998). In 2003, a communication on Integrated Product Policy (IPP) (EC 2003) was adopted which outlined strategies for decreasing environmental impacts from products throughout their life cycle. The IPP effectively introduced the "life cycle thinking approach" where the environmental impacts of products should be considered from "the cradle to the grave", and in an integrated manner. In this way, the shifting of environmental burdens between different life cycle stages or sectors can be avoided and policy coherence when dealing with the diverse impacts

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of production and consumption can be ensured. The IPP was followed by the Ecodesign Directive on energy-using products (EC 2005a, 2009a) and by the Sustainable Consumption and Production Action Plan (EC 2008a), which focused on how to improve the environmental performance of products and technologies and foster well-informed decisions by consumers. Product policies based on life cycle thinking were therefore developed. However, as no single policy can be capable of addressing all product and sector specific challenges, it was recognised that a combination of pull (voluntary) and push (mandatory) tools is needed (see Fig. 1).

The common denominator for policy tools is that they regulate environmental aspects for different life cycle stages of products. However, their scope and intended ambition levels differ. While Ecodesign (EC 2005a, 2009a) serves to push the market towards more sustainable products through the implementation of mandatory minimum requirements, Green Public Procurement (GPP) (EC 2008b) and EU Ecolabel criteria (EC 2010) aim to pull the market by promoting the production and consumption of more sustainable product options. In particular, the Ecolabel is a type-I environmental label (ISO 2018) that can bring added value for companies that invest in eco-innovation and want to communicate the improved environmental performance of their products or services to consumers (Iraldo and Barberio 2017). In contrast, the Energy Label (EC 2017a) applies to the entire spectrum of relevant products and allows consumers to choose between different product performance levels.

Life cycle assessment (LCA) (ISO 2006a, b) is a key tool to identify how environmental requirements should be developed and to understand any related impacts and trade-offs (Cordella et al. 2015; Cordella and Hidalgo 2016). In general, this needs to be embedded in a broader analysis of legislative, techno-economic and social aspects (e.g. product quality, inherent safety of materials (Cordella et al. 2009; Cordella et al. 2012)) that are not conventionally covered or fully integrated in LCA. More recently, the Product Environmental Footprint (PEF) guide (EC 2013a) has developed harmonised rules for quantifying relevant environmental impacts of products through their life cycle. A pilot phase has been conducted to test the process for developing product and sector category rules, approaches for verification and vehicles for communicating the environmental performance of products (EC 2013b).

To date, Ecodesign and Energy Label are mandatory tools which have been specifically targeted at energy-using and energy-related products with a particular focus on energy consumption during the use phase. EU Ecolabel and GPP generally have a much wider scope both in terms of products and type of requirements, which in part stems from their voluntary nature. These tools can cover the production site (e.g. emissions to air and water, energy consumption), product composition (e.g. exclusion of certain substances due to their inherent hazardous properties), use phase (e.g. energy efficiency, fitness for use),or the end of life (e.g. design for ease of recycle). Service aspects such as take-back and repair can also be relevant, especially in GPP.

The recent Circular Economy Action Plan (EC 2015a), which promotes transition in the EU towards a more circular economy, has remarked the importance of material efficiency requirements in discussions about product sustainability. However, effort is needed to stimulate the systematic and coherent implementation of material efficiency aspects in product policy tools. To this end, the European Commission issued Mandate 543 (EC 2015b) to CEN/CENELEC to develop standards with which to harmonise concepts, methods and

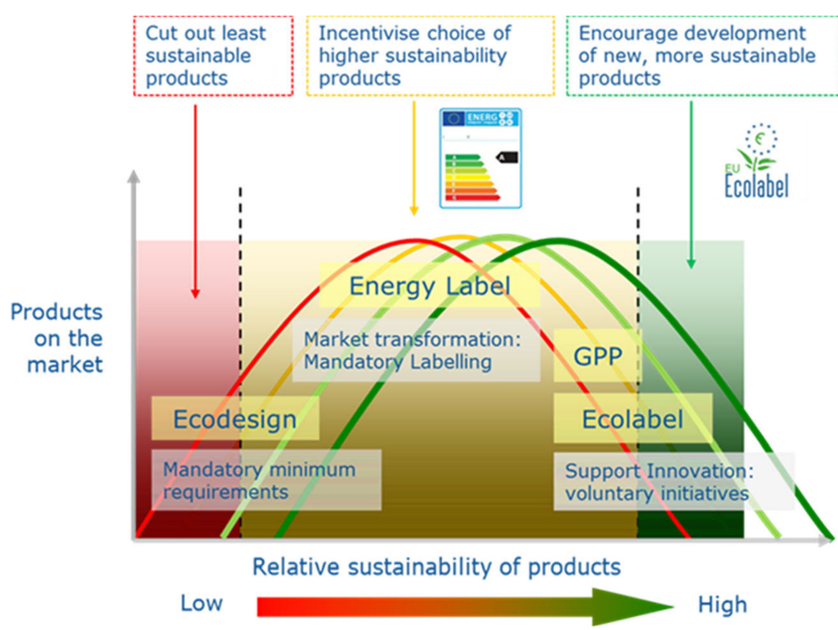

Fig. 1 Product policy tools and sustainability of products on the market

nomenclatures to apply in the assessment of material efficiency aspects of energy-related products (CEN/CLC/JTC 10 2019).

The goal of this paper is to analyse existing material efficiency requirements set for EU Ecolabel products. A definition and classification system is presented to support a coherent discussion of such aspects in a hierarchically structured way. Current practice, limitations and possible improvements are described, as well as potential synergies with other EU policies and initiatives. As a voluntary tool targeting front-runners, an analysis of the EU Ecolabel criteria can provide a reference base and a potential benchmark for design, communication and policy activities aimed at promoting the material efficiency of products and contributing to the implementation of a more circular economy.

2 Methods

In order to analyse to what extent material efficiency aspects are recognised by the EU Ecolabel and how this could be potentially improved, it is first necessary to have a clearer understanding of what is meant by the term "material efficiency", then to use this definition to screen against a defined number of EU Ecolabel product groups, and finally to cross-check against other EU policies and legislation to identify possible synergies or barriers to further the promotion of material efficiency–related criteria.

2.1 Definition and classification of material efficiency aspects

The analysis of material efficiency aspects entails dealing with a broad spectrum of concepts. Analogous to the definition of "energy efficiency" (EC 2012a), "material efficiency" can be defined as the ratio between the performance output of a product, service or energy system and the input of materials required to provide such output. It is thus apparent that material efficiency can increase either by improving the performance or reducing the input of materials to provide a certain performance.

From a system perspective, material efficiency can be considered a range of strategies relating to the use and management of resources throughout the life cycle of a product or service and which aims to minimise material consumption, waste production and their related environmental impacts (Allwood et al. 2011; Huysman et al. 2015), without affecting functionalities negatively.

Figure 2 shows alternative routes for products before their final disposal in landfill, which can contribute to improving their material efficiency. At the macro-scale level, material efficiency can mean moving from a linear model of production and consumption (i.e. from virgin material extraction, to short/single use of products and final disposal in landfill) to a more circular model, where input of virgin materials can be reduced and landfill disposal is minimised, or at least kept controlled in a growing economy. A framework of indicators which could be potentially used to quantify such a transition at different levels has been presented in Huysman et al. (2015).

Material efficiency strategies can be quite well mirrored by the hierarchical approach set out by the Waste Framework Directive (Allwood et al. 2011; Bakker et al. 2014; EC 2008c, 2018a), as shown in Fig. 3. The waste hierarchy aims at reducing the waste output and its disposal in landfill. Material efficiency goes beyond and promotes also the prevention of material consumption. Taking the example of waste management, a hierarchy of strategies has been drawn for material efficiency aspects at the product level:

1. Reduction: the highest priority can be assigned to the direct reduction of the quantity of materials used for products and services. This can be promoted through design and manufacturing practices which address
   (a) The material resources used in products, e.g. through the integration of functionalities (e.g. multifunctional devices allowing printing and scanning), the dematerialisation of products and services, the avoidance of design over-specifications, and design optimisation and lightweighting processes (Allwood et al. 2011), as done already in the car industry (Traverso et al. 2013). The use of recycled materials has been addressed in the third category related to recycling because it affects the consumption of virgin materials at the system level, but does not necessarily imply a reduction in the mass of the product.
   (b) A more efficient use of material resources in the manufacturing process (Allwood et al. 2011), including the minimisation of the manufacturing waste.
2. Reuse: this category aims at prolonging the use of products, or parts of products, preventing the need for new products and ultimately saving material resources and avoiding waste production (Bakker et al. 2014), due to the prolongation of the lifetime of a product or of its parts. This can be promoted through the consideration of a range of design aspects allowing the retention of product value by
   (a) Making products/parts more durable (e.g. enhancing resistance and duration under defined conditions of use (Alfieri et al. 2018a, b)).
   (b) Facilitating repair, reuse and upgrade (RRU) operations (Cordella et al. 2018), as well as refurbishment and remanufacturing processes (Russell 2018).
3. Recycling/recovery: as a last option, the residual value of products and materials can be recovered at the end of life

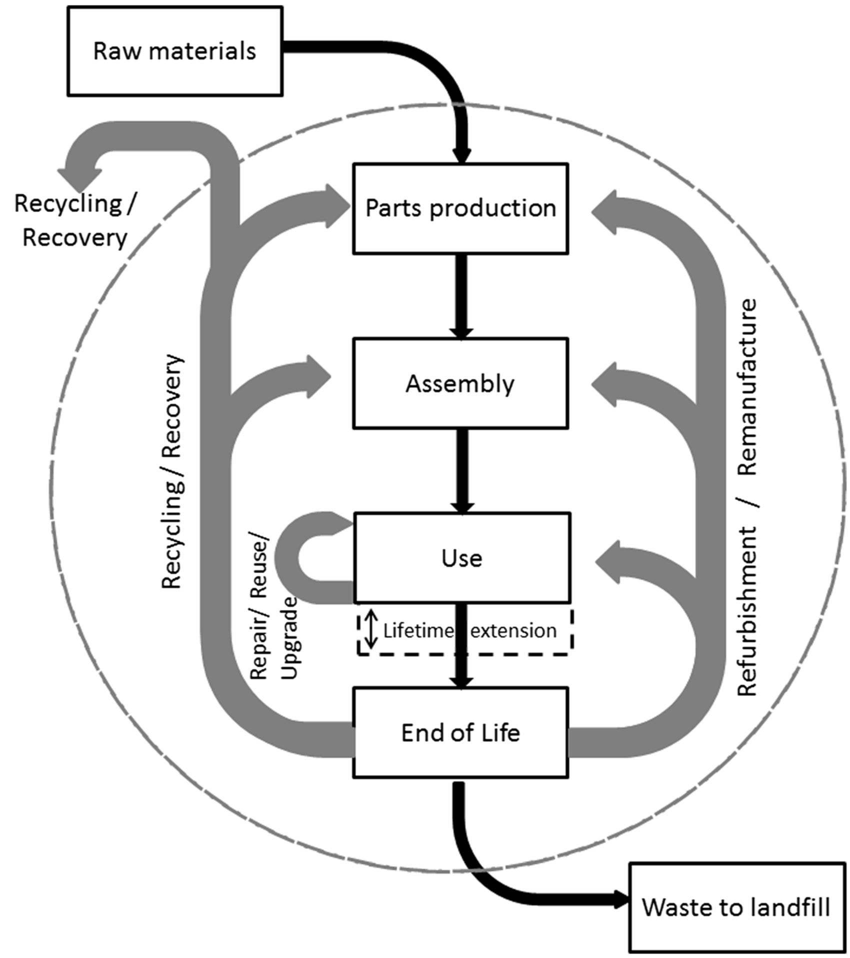

Fig. 2 Material efficiency aspects in the context of a product life cycle

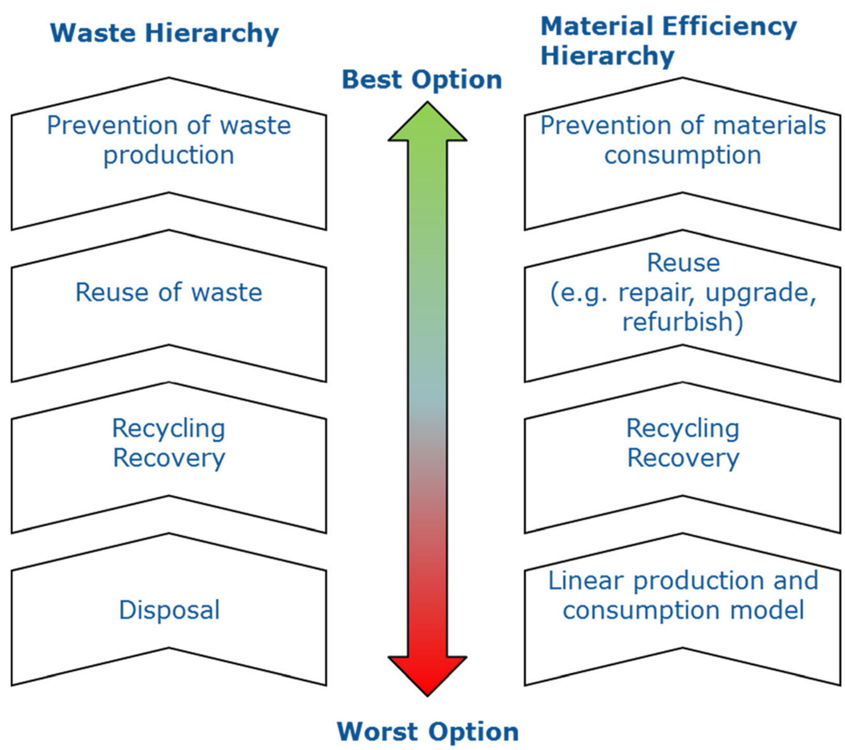

Fig. 3 Analogy between waste and material efficiency hierarchies

through recycling and recovery processes. Recycling is beneficial since it can reduce the consumption of virgin materials. A distinction between non-destructive and destructive (conventional) recycling can be made depending if the targets of the recycling operation are parts or materials, respectively (Allwood et al. 2011). Destructive recycling requires dismantling of the product to separate its material constituents and reprocessing recyclates prior to their re-entry into the material supply chain (e.g. paper to be deinked and pulped, plastics to be re-melted and extruded, steel to be smelted). For the parts where recycling is not feasible, waste materials should be recovered as far as possible for other purposes, such as energy production. Annex II of the Waste Framework Directive (EC 2008c, 2018a) sets out a non-exhaustive list of recovery operations. In any case, waste has to undergo safe disposal operations (see Annex I of the Waste Framework Directive), which may require selective treatments, as in the case of electronic waste (EC 2012b). Reusability/recyclability/recoverability (RRR) rates can be used to indicate the percentage of the mass of a product that is expected to be reused/recycled/recovered at the end of life (Huysman et al. 2015). Recycling and recovery can be promoted by

(a) Design approaches aimed at improving the recyclability of products.
(b) An increase in the target content of recycled materials in products.
(c) The implementation of take-back systems to return products at the end of life.

The classification presented above has been applied for the clustering and analysis of EU Ecolabel requirements on material efficiency. Since the terminology specifically used to describe material efficiency aspects has evolved separately in different sectors, a series of relevant terms used in this analysis is defined in Table 1.

Table 1 Definitions of specific terms related to material efficiency aspects as used in this work

Term	Definition
Disassembly	The process by which a product can be separated into its parts in a non-destructive way.
Dismantling	The process by which a product can be separated into its parts and materials in a destructive way.
Durability	The ability of a product to function as required under defined conditions of use and maintenance until a limiting state due to a technical failure is reached. Note: a broader definition of durability could include repair, upgrade and socio-economic considerations.
Lightweighting	The reduction of the quantity of materials in a product without compromising its ability to meet its minimum functional requirements.
Manufacturing waste minimisation	The reduction of the waste produced during the manufacture of a product that is not reused, recycled or recovered.
Recoverability	The degree to which parts can be separated at end of life (for depollution, reuse or energy purposes).
Recovery	Operations by which waste materials are reprocessed into products, materials or substances used for the original or other purposes.
Recyclability	The degree to which a product contains materials that can be separated and recycled at the end of life.
Recycle	Recovery operation by which waste materials are reprocessed into products, materials or substances used whether for the original or other purposes, excluding backfilling and energy production.
Refurbishment	Treatment or a modification of a product, or parts of a product, to increase or restore its performance and/or functionality or to meet applicable technical standards or regulatory requirements, with the result of making a fully functional product to be used for a purpose that is at least the one that was originally intended.
Remanufacturing	The treatment or modification of a product, or parts of a product, in industrial processes to restore it to original as new condition and performance, or better. This is done in line with specific technical specifications, including engineering, quality and testing standards, and typically yields fully warranted products.
Repair	The process of returning a faulty product, or a part of a product, to a condition where it can fulfil its intended use.
Reparability	The ease with which a product/part can be repaired.
Reusability	The potential for a product, or its parts, to be reused by another user and for the same purpose.
Reuse	Operation by which a product, or its parts, continue to be used for the same purpose for which they were conceived.
RRU	Reparability, reusability and upgradability.
Upgradability	The ease with which a product/part can be upgraded.
Upgrade	The process of enhancing the functionality, performance, capacity or aesthetics of a products or a part of a product.

It should be noted that the EU Ecolabel covers also other aspects that go beyond the scope of this paper, such as fitness for use, emissions to air/water and energy consumption in the use phase. In particular, fitness for use refers to the suitability of a product to fulfil its intended functions and purposes (e.g. for detergents, it would be its effectiveness to remove dirt from laundry up to an acceptable standard). Fitness for use could be considered as relevant for material efficiency since it could reduce the likelihood of consuming more product units for the same purpose (e.g. in the case of diapers and tissue papers with reduced absorbency). However, this has not been explicitly included in the analysis since it is a minimum entry level requirement that any EU Ecolabel product has to comply with in order to ensure the satisfactory performance and quality of products.

2.2 Products included in the analysis

In September 2018, the EU Ecolabel applied to 26 different product groups and counted with more than 2000 valid licences covering over 70,000 products and services available on the market (EC 2018b). All product groups are analysed, which can be split into five macro-categories of products (see Table 2):

1. Energy-using products
2. Multi-material products
3. Biomass-based products
4. Products that are mixtures
5. Products that are services

Table 2 Screening of EU Ecolabel requirements for material efficiency aspects

Product group		Reduction		Reuse		Recycling/recovery		
		Use of material resources	Manufacturing waste minimisation	Durability	RRU	Recyclability	Recycled content	Take-back system
Energy-using products	Computers (EC 2016a)			x	x	x	x	
	Televisions (EC 2009b)				x	x		
	Water-based heaters (EC 2014a)				x	x		x
Multi-material products	Absorbent hygiene products (EC 2014b)		x					
	Bed mattresses (EC 2014c)			x	x	x		
	Footwear (EC 2016b)			x			x	
	Furniture (EC 2016c)			x	x	x	x	
	Hard coverings (EC 2009c)		x				x	
	Textiles (EC 2014d)			x			x	
Biomass-based products	Converted paper (EC 2014e)		x			x	x	
	Graphic paper, tissue paper and tissue products* (EC 2019)						x	
	Printed paper (EC 2012c, 2012d)		x			x	x	
	Soil improvers and growing media (EC 2015c)						x	x
	Wood-, cork- and bamboo-based floor coverings (EC 2017b)			x	x		x	
Products that are mixtures	Detergents for dishwashers (EC 2017c)	x				x	x	
	Hand dishwashing detergents (EC 2017d)	x				x	x	
	Hard surface cleaning products (EC 2017e)	x				x	x	x
	Industrial dishwasher detergents (EC 2017f)	x				x	x	x
	Industrial laundry detergents (EC 2017g)	x				x		x
	Laundry detergents (EC 2017h)	x				x	x	
	Lubricants (EC 2018c)						x	
	Paints and varnishes (EC 2014f)	x		x				
	Rinse Off Cosmetics (EC 2014g)	x				x		
Products that are services	Indoor cleaning services (EC 2018d)	x				x		
	Tourist accommodation services (EC 2017i)	x	x	x	x	x		

*In January 2019, the EU Ecolabel for graphic paper and for tissue paper and tissue products were published in a single Decision with two annexes–hence, 25 product groups are listed above instead of 26

2.3 Cross-check with EU policies and initiatives

Once the review of the material efficiency aspects currently promoted by the EU Ecolabel has been carried out, other EU policies and initiatives need to be considered in order to identify any possible synergies and barriers that would encourage or discourage further promotion of material efficiency, as well as legislation that could make material efficiency redundant.

The product policies and initiatives considered are GPP (EC 2008b), Ecodesign (EC 2009a), Energy Label (EC 2017a) and the Product Environmental Footprint (EC 2013a).

In addition, the analysis also include the Circular Economy Action Plan (EC 2015a), legislation on safety (EC 2001, 2006a, 2014h), hazardous substances (EC 2004, 2006b, 2008d, 2011a), consumer rights (EC 1999, 2011b) and products' end of life (EC 2008c, 2012b, 2018a), as well as more specific product-related topics (packaging (EC 1994), priority materials (EC 2017j, 2017k), batteries (EC 2006c) and vehicles (EC 2000, 2005b, 2011c)).

3 Material efficiency aspects in the EU Ecolabel

In accordance with the approach presented in section 2, material efficiency requirements that products have to fulfil to be awarded the EU Ecolabel have been categorised as shown in Table 2. Further details can be found in the Commission Decisions referenced in the table. An overview of how material efficiency strategies could be systematically addressed in the EU Ecolabel is shown in Table 3.

3.1 Reduction

Material efficiency options currently implemented in EU Ecolabel requirements for this strategy typically cover lightweighting, efficiency of use and minimisation of the production waste.

Lightweighting aspects are mainly associated with product groups that are mixtures. A closer look at detergents and for rinse-off cosmetics reveals that all these product groups have requirements on packaging efficiency (e.g. a maximum limit of weight of packaging per volume of product). Even though the LCA results did not reveal packaging as a significant contributor to overall environmental impacts, still the packaging was considered important due to high overall amounts of plastic packaging waste resulting from those products. A different approach for saving resources is instead applied to paints and varnishes, where a minimum spreading rate is set (L/m^2). Lightweighting requirements have not been developed so far for more complex products. This would require the comparison of different materials and design options and the

Table 3 Examples of material efficiency aspects linked to EU Ecolabel requirements

Strategy	Options
Reduction	Use of material resources in products: Design optimisation and lightweighting Selection and sourcing of resources (e.g. critical raw materials) Manufacturing process: Efficiency in the use of materials Minimisation of manufacturing waste
Reuse	Durability: Stress resistance Endurance Reliability Extended guarantee Provision of information about use and maintenance Reparability, Reusability and Upgradability (RRU): Product design (e.g. ease of disassembly of target parts) Spare parts availability Upgradability Data transfer and deletion functionalities Provision of repair, reuse and upgrade information
Recycling/recovery	Recyclability: Recyclability thresholds Restrictions on substances/materials hampering recycling Marking of materials/parts Ease of dismantling of target parts and provision of instruction Information on the presence of specific substances in the product (e.g. hazardous substances) Recycled content: Minimum content of recycled materials Take-back systems

assessment of the related trade-offs. Setting fair thresholds that do not limit or penalise future technical solutions is not straightforward.

Requirements related to waste minimisation focus on waste production rates at the factory. Waste production limits are set as a function of the production volume by weight and are nuanced for the type of product (e.g. 20% for envelopes in converted paper) or for the type of process (e.g. 23% for sheet offset printing, 10% for coldest newspaper printing and 15% for gravure printing).

No restrictions are usually applied to specific materials, although this could be explored in the future for critical raw materials (CRMs) and minerals from conflict-affected and high-risk areas (EC 2017j, 2017k). Only the reduction of sources of inherent hazardous substances is an aspect that is currently addressed in a systematic way through EU Ecolabel requirements (EC 2010).

3.2 Reuse

Material efficiency options currently implemented in EU Ecolabel requirements for this strategy typically address the durability, reparability, reusability and upgradability of products.

Durability aspects are predominantly associated with multi-use and long life products that could include complex articles (the more complex an article, the more parts that can break and render the entire product obsolete). Durability requirements mainly focus on resistance to stresses, for example, abrasion resistance for textile fabrics and furniture upholstery, resistance to indentation for wooden floor coverings, scratch resistance for coated furniture pieces, height and firmness endurance for bed mattresses and resistance to shock for data storage drives of computers.

Setting minimum thresholds on endurance and reliability over the lifetime of products is more challenging because of the difficulties associated with the testing and verification of such information. The actual effectiveness of such requirements should also cover functional aspects in order to account for loss of performance over time (Alfieri et al. 2018b), and be supported by appropriate testing procedures. So far, more advanced requirements in this area have been only set for computers.

Adequate product guarantees can be another manner to handle durability indirectly. In the EU Ecolabel this is required for batteries in notebooks (2 years), computers (3 years), furniture (5 years), wooden floor coverings (5 years) and mattresses (10 years).

Other requirements related to the reuse of products involve the incorporation of design features for the ease of disassembly of products, together with a commitment to make spare parts available and provide information on how to carry out maintenance and repairs. All three of these factors should be used together, and in a systematic way, in order to make re-use or repair a potential option in the real world. Although important for energy-related products and complex articles made of multiple materials and/or parts, these types of requirements are fundamentally irrelevant for other product groups, such as tissue paper and mixtures.

With respect to the spare parts, important issues are their availability, cost and delivery time over a sufficiently large period. For instance, the availability of spare parts after the purchase of the product must be 10 years for water-based heaters, 7 years for televisions, 5 years for computers, monitors and new furniture. Nevertheless, cost and time of delivery are not specified in any detail.

The energy-related products regulated in Ecolabel are examples of electrical and electronic equipment (EEE) that can at some point become obsolete. Especially for these products, the coverage of aspects related to reusability and upgradability (e.g. software and firmware update, deletion and transfer of personal data) are essential to avoid premature obsolescence, support the promotion of second hand markets, and prolong the product lifetime.

3.3 Recycling/recovery

Material efficiency options currently implemented in EU Ecolabel requirements for this strategy usually cover design aspects aimed to maximise the potential for recycling the product, so-called "design for recyclability".

For products which are complex articles, this inevitably relates to the ability to easily separate the product into different materials (e.g. metal, plastic, textiles and wood), which can require restrictions on substances, fulfilment of design characteristics and provision of information. Design approaches facilitating the ease of dismantling of EEE products into different parts (e.g. parts that are rich in valuable materials and/or hazardous substances and parts that are relatively low-value plastics) can also assist greatly the potential recovery of value from this waste stream. This can be assisted also through the marking of parts and materials, as done for plastics in computers.

For simple articles like paper products, this is not practical except when the paper article is printed or converted, because only then choices can be made that affect the product recyclability (e.g. degree of varnish or lamination applied and type of inks used). With product groups that are mixtures, the design for recyclability is mainly focused on the choice and combination of polymers in plastic packaging, labels and sleeves.

Moreover, minimum thresholds on recycled content are sometimes required for specific materials, based on technical and market conditions. Examples are the minimum 10% average post-consumer plastic required in computers (except circuit boards and display optical plastics), the minimum 30% average plastic-recycled content in furniture (if plastic accounts for at least 20% of furniture product weight), the minimum 70% recycled paperboard in packaging for hard coverings. However, an optional approach is taken in some cases, for instance, when dealing with requirements for wood (relevant to the paper products, furniture and footwear) where a requirement for at least 70% of sustainable wood/fibre content is set and where recycled wood or paper is considered equivalent to virgin wood or fibres from sustainably managed forests for this purpose.

It could be argued that the incorporation of recycled material also constitutes a material reduction (on virgin material consumption). However, requirements on the recycled content of a certain material work when there is sufficient supply of that recycled material. For instance, minimum recycled content for paper has not been required in the EU Ecolabel for graphic paper and tissue paper based on the argument that waste paper demand already exceeds market supply. Similar considerations apply to metals (e.g. in furniture).

When the market of a certain recycled material needs to be stimulated, it could be more appropriate to quantify recyclability targets for such material. However, requirements in this direction have not been set so far in the EU Ecolabel criteria (they are currently under discussion for some products). Moreover, from a life cycle perspective, the distance between recycling plants and manufacturers is also relevant, as the environmental impacts due to long-distance transport could counterbalance the potential benefits of recycling. Blengini and Garbarino (2010) estimated that the use of recycled aggregates (when compared to natural aggregates) can remain environmentally beneficial up until the point when the transport distance for recycled aggregates becomes 2–3 times longer than that for natural aggregates.

Another important aspect refers to the potential presence of hazardous substances which can hamper the recycling of materials. Articles 6(6) and 6(7) of the EU Ecolabel Regulation (EC 2010) specifically exclude the awarding of the EU Ecolabel to goods that contain certain hazardous substances, including Substances of Very High Concern (SVHCs). Articles 7 and 33 of the REACH Regulation (EC 2006b) oblige suppliers and manufacturers to inform their downstream customers upon request if the content of any individual SVHC exceeds 0.10% by weight in any article they supply. Although it is legal to sell products on the EU market that contain SVHCs in concentrations exceeding 0.10%, such products would not qualify for the EU Ecolabel. It is a significant challenge for producers who buy virgin materials and chemicals to ensure continued compliance with customer requests for SVHC information on their products. However, when dealing with recycled inputs there are some major doubts about legacy substances that may be present (e.g. creosote in recycled wood and cadmium or lead in recycled PVC). Testing protocols may exist for a few individual substances in specific materials but this cannot be extended to all SVHCs and cannot be applied to each batch (e.g. of recycled plastic) that is delivered. The two extremes of possible approaches are

1. To treat recycled materials in the same way as virgin materials and effectively prevent the recycling of materials due to excessive testing costs. This is a restrictive approach that would penalise recycled materials in the short to medium term. However, all legacy restricted compounds will sooner be removed entirely from material loops.
2. To not place any particular restrictions on the recycled materials, to promote their use. Legacy-restricted compounds could gradually diminish over time at a sectorial level.

These two extremes each have their own advantages and disadvantages and serve to highlight a potential source of discrepancy in EU initiatives (i.e. the Circular Economy Action Plan and the EU Ecolabel). The most appropriate option, while being inevitably somewhere in the middle, will depend on the nature of the substance, the type of use of relevant articles and the exposure risk that exists to users or the wider environment.

Finally, with the notable exception of water-based heaters, the promoted take-back systems focus on business to business relationships (i.e. return of packaging of industrial/institutional cleaning products or collection of growing media from professional horticultural applications). The take-back of water-based heaters could be of considerable interest to producers in any case due to the potential to cannibalise old products for spare parts and facilitate repair operations elsewhere.

3.4 Possible trade-offs and limitations in the definition of material efficiency requirements

The development of material efficiency requirements should be supported by a solid evidence basis. LCA is a key tool for understanding which design options can be more beneficial from an environmental perspective and if relevant trade-offs exist.

In theory, availability of information for a statistically representative sample of products could allow for the definition of environmental thresholds based on life cycle indicators. However, the state-of-the-art is that this approach presents limitations such as a wide variety of product designs, qualities and functionalities on the market that lie within the same product group scope; lack of available primary or even secondary data; evolving LCA methods and tools and the associated uncertainty; low availability of robust and fair assessment and verification procedures and the duration of the criteria development process. Furthermore, other considerations are also important in order to understand the economic, social and market consequences for particular products, materials or sectors. Benefits and any trade-offs associated with different material efficiency options can be assessed adopting a practical life cycle thinking (LCT) approach based on LCA and complemented by other product-related information (Cordella and Wolf 2015).

All material-based products have an inherently physical limit for lightweighting. Although lightweighting could bring direct and quantifiable environmental benefits from an LCA perspective, this should be considered in the context of the overall impacts of functionally equivalent products. For example, substituting a 10-kg set of steel table legs for a 6-kg set of aluminium table legs, with the fulfilment of the same technical specifications, may actually increase the overall environmental impacts of the table if virgin aluminium is used instead of virgin steel (Norgate et al. 2007). Further variations may depend on any recycled content allocated to the steel or aluminium used. Moreover, additional limitations to lightweighting may be associated with the need of fulfilling minimum technical specifications for product safety, performance and durability.

There can be trade-offs also between recycled content and safety or technical performance. For example, with a safety first approach, there is the tendency that bags, components or products made predominantly from recycled plastic (EC 2015d) will be thicker or bulkier to compensate for doubts about batch consistency that may impact on the physical properties of the product. This was one of the main reasons why the packaging efficiency requirements set for EU Ecolabel cleaning products did not apply if the recycled content exceeded 80%.

Moreover, the effects of alternative options should be assessed taking into account market evolution. Depending on the relative magnitudes of impacts due to production, use phase and end of life, it could be either more convenient to prolong the use of energy-related products or to replace them with more efficient products (Alfieri et al. 2018a; Cordella et al. 2018; Iraldo et al. 2017; Tecchio et al. 2016).

Finally, in some circumstances, actions that improve the durability of a product (e.g. gluing) could have consequences at material level and/or compromise reparability. The EU Ecolabel tends to focus on the extent to which design features have been incorporated into products that would make interventions as reuse, repair and refurbishment as feasible as possible in the future.

4 Cross-check of material efficiency aspects with EU policies and initiatives

From Table 2, it is clear that every EU Ecolabel product group has some requirements on material efficiency. When considering interactions between the EU Ecolabel and other EU policies and initiatives (see Table 4), different types of relationships can be categorised:

I. Market-focused symbiosis (see also Fig. 1): In this case, the EU Ecolabel can act as a flagship policy to promote material efficiency front-runners with a supply side signal. The same material efficiency aspects can be addressed in a similar way in GPP (EC 2008b) and Ecodesign (EC 2009a), although at a different ambition level. When applicable, the mandatory nature of the Ecodesign Directive obliges producers to place on the market products that fulfil minimum requirements. The GPP policy tool, when setting relevant material efficiency criteria, instead sends a demand side signal and has the flexibility to set less ambitious requirements than the EU Ecolabel (especially via "core level" technical specifications) but reward more efficient products (via award criteria). Communication of material efficiency aspects could be potentially integrated also in the Energy Label (EC 2017a).

II. Policy synergies: These are the case when any promotion of material efficiency in the EU Ecolabel is well aligned with the general objectives of other policies and initiatives, in a way that the application of one compliments the objectives of the other. In general, the material efficiency aspects discussed in this analysis are addressed through the Circular Economy Action Plan (EC 2015a). As presented earlier, this is a major policy effort to promote the durability and reparability of products and other design side aspects such as selection of materials, recyclability and the incorporation of recycled content into products. From a narrower perspective, the Waste Framework Directive (EC 2008c, 2018a) is arguably the most closely related with material efficiency in this respect, as highlighted in Fig. 3, and is sufficiently broad to apply to all EU Ecolabel product groups. The Packaging Directive (EC 1994) and the WEEE Directive (EC 2012b) also have mutually inclusive objectives but are limited in scope to packaging and electronic/electrical equipment respectively. However, there are other areas where EU policies and initiatives can serve as potential source of inspiration for the EU Ecolabel, such as CRMs and conflict minerals (EC 2017j, 2017k), due to the geopolitically sensitive issues involved in their supply, as well as batteries (EC 2006c) and vehicles (EC 2000, 2005b, 2011c), for the management of hazardous substances and the correct disposal, collection and recycle of products and the setting of RRR targets.

III. Checks and balances: These are examples of policies and initiatives that can put a practical limit to material efficiency or that assess what the effect of changing the material efficiency is on overall environmental impacts. Concerns about hazardous substances in recycled material streams present a significant barrier to any

Table 4 Policies and legislation linked to EU Ecolabel material efficiency requirements and included in the analysis

	Policy/initiative and possible interactions with the EU Ecolabel
Market-focussed symbiosis	GPP (EC 2008b): a policy tool which public authorities can use to procure more environmentally friendly goods and services. Any relevant material efficiency aspects from EU Ecolabel can be incorporated directly into invitations to tender. Strong synergies can be possible in cases where the public sector is an important part of the market (e.g. hard coverings, furniture, computers).
	Ecodesign (EC 2009a) and Energy Label (EC 2017a): although Ecodesign and Energy Label requirements have focused primarily on energy efficiency, mandatory measures on material efficiency aspects have begun to be introduced because of the recognised importance of making the economy more circular.
	Although the EU Ecolabel experience can be of inspiration, the ambition level of Ecodesign should be evaluated carefully due to the mandatory nature of this policy (i.e. EU Ecolabel front runners vs. Ecodesign cut-off of the market). Communication of material efficiency aspects could be potentially integrated on the Energy Label.
Policy synergies	Circular Economy Action Plan (EC 2015a): a holistic approach is presented covering design, production processes, consumption, waste collection and conversion of waste to resources. Relevant priority areas to the existing EU Ecolabel product groups include plastic recycling rates, sustainable sourcing of bio-based materials, reuse of construction and demolition waste (CDW) and recycling of CRMs from electronic products.
	Waste Framework Directive (EC 2008c, 2018a): the core objective is basically to improve material efficiency but looking from the broader perspective of waste generated by society. This directive provides a waste management hierarchy and promotes Extended Producer Responsibility (EPR). Material efficiency requirements of the EU Ecolabel (such as take-back systems) can be seen as consistent and synergistic with the objectives of the Waste Framework Directive.
	Packaging and Packaging Waste Directive (EC 1994): essentially the same approach as the Waste Framework Directive but specifically focussing on the packaging. Requirements on packaging depend on its environmental importance for a product and can cover different aspects.
	WEEE Directive (EC 2012b): especially focussed on design for disassembly and recyclability aspects of material efficiency at the end of life stage of EEE products. Annex VII of WEEE lists a series of materials and components to remove and collect separately for depollution at the end of life. Extraction of such parts should be facilitated through, for instance, provision of information for users and recyclers (see Art. 14 and 15 of WEEE) and product designs allowing the easy identification and disassembly of such parts (see Art. 4 of WEEE). Currently, it is only relevant to EU Ecolabel computers and televisions but requirements are complementary.
	Priority materials (such as CRMs and minerals from conflict-affected and high-risk areas (EC 2017j, 2017k)): a complete reduce-reuse-recycle approach to material efficiency could be justified in the EU Ecolabel criteria for relevant CRMs and conflict minerals (e.g. cobalt in Li-ion batteries for laptops, indium in screens). Such a complementary approach would bring simultaneous social, environmental and potential economic benefits and is supported by Article 6 of the EU Ecolabel Regulation. The promotion of recyclability aspects would also complement the aims of the WEEE Directive.
	Batteries Directive (EC 2006c): prohibits the marketing of batteries containing certain hazardous substances, defines measures to improve collection and recycling rates and sets targets for collection and recycling rates. The Directive also sets out provisions on labelling of batteries and their removability from equipment.
	Legislation on vehicles (EC 2000, 2005b, 2011c): Directive 2000/53/EC sets clear targets for dismantling and recycling of end of life vehicles and promotes the manufacture of new vehicles without lead, mercury, cadmium and hexavalent chromium, which could hinder reuse, recyclability and waste recovery from vehicles. The material efficiency of the motor vehicle sector is further regulated through (i) the Directive 2005/64/EC on the type-approval of motor-vehicles with regard to their reusability, recyclability and recoverability; (ii) the Commission Regulation (EU) No 566/2011 as regards access to vehicle repair and maintenance information.
Checks and balances	Hazardous substances (EC 2004, 2006b, 2008d, 2011a): CLP and REACH are the two key elements referred to in the implementation of Articles 6.6 and 6.7 of the EU Ecolabel Regulation, which foresees the restrictions on chemicals based on their hazardous properties. Additional legislation addresses specific products, such as RoHS for EEE. Restrictions on hazardous materials may facilitate the recycling process but may also present a barrier to the incorporation of recycled materials in new products.
	Consumer Sales Directive (EC 1999, 2011b): ensures a minimum guarantee of 2 years in all EU Member States for consumer goods and repair or replacement if goods are faulty. It indirectly encourages more durable goods that can be taken back and repaired if necessary. The EU Ecolabel requirements promote similar types of guarantees but for longer periods. A longer guarantee is a kind of proxy for better durability.
	PEF (EC 2013a): sets common rules for LCA assessment of defined product groups. Could be used to assess the importance of any material efficiency aspects on the environmental footprint of the product and to potentially identify unexpected trade-offs that may occur via the promotion of material efficiency (e.g. lightweighting via substitution of one material for another).

In addition, the analysis also include the Circular Economy Action Plan (EC 2015a), legislation on safety (EC 2001, 2006a, 2014h), hazardous substances (EC 2004, 2006b, 2008d, 2011a), consumer rights (EC 1999, 2011b) and product end of life (EC 2008c, 2012b, 2018a), and more specific product-related topics (packaging (EC 1994), priority materials (EC 2017j, 2017k), batteries (EC 2006c) and vehicles (EC 2000, 2005b, 2011c)) mandatory requirement for recycled content in EU Ecolabel products (see section 3.3 for more details). Material efficiency in product design should not be prioritised over product safety or functionality. Even for products where clear safety or fitness for use standards have not been defined, the General Products Safety Directive (EC 2001) and the Consumer Rights Directives (EC 2011b) still applies, as well as legislation on hazardous substances (EC 2004, 2006b, 2008d, 2011a). Although improved material efficiency can be generally perceived as being associated with environmental benefits, simple metrics (e.g. the content of recycled material) could lead to unexpected outcomes. In this respect, the application of an LCA approach, such as the Product Environmental Footprint (EC 2013a), could help to better understand possible trade-offs in such situations.

5 Conclusions

An overview of material efficiency aspects addressed in voluntary EU Ecolabel criteria for 26 different product groups has been presented in the context of a classification system based on a hierarchy of strategies: reduction, reuse and recycling/recovery. The main findings are

1. Reduction: Requirements for lightweighting have been mainly limited to packaging of mixtures and not to products due to the major difficulty of defining thresholds for the material design of products. For some products, the reduction option also addresses the amount of waste generated in the production plant.
2. Reuse: Durability of products in terms of resistance to stresses has been broadly implemented. A higher durability can extend the useful lifetimes of products, with potential benefits for consumers and the environment. Product lifetime extensions should not come at the expenses of functional losses and should be backed up by suitable testing procedures and/or guarantees. Although not examined in detail in this work, fitness for use requirements are set systematically in the EU Ecolabel, which somehow address the functionality of products and can prevent overconsumption or the premature replacement of products. Repair, reuse and upgrade of products are also addressed in products which are articles. To be enabled, they need to be backed up by appropriate requirements on product design, availability of spare parts and provision of clear information. Upgradability becomes in particular important for quickly developing products as ICT devices.
3. Recycling/recovery: Although being identified as the lowest priority material efficiency strategy, requirements associated with the recycling of products are the most commonly implemented across EU Ecolabel product groups. These mainly focus on the ease of dismantling of products in such a way that target parts can be easily extracted from the product. Requirements that promote the incorporation of recycled content into EU Ecolabel are hindered due to concerns about recyclate batch consistency and the requirements of Articles 6(6) and 6(7) of the EU Ecolabel Regulation. Quantitative targets on the recyclability and recoverability of materials could be explored to stimulate the market for some recycled materials.

The analysis of how material efficiency aspects can interact between different policies has shown that the promotion of material efficiency in the EU Ecolabel is complementary with a number of other EU policies and initiatives. Areas where similarities and synergies between different policies could be exploited have been identified, as well as barriers limiting the possibilities to improve the material efficiency of products.

This analysis of material efficiency aspects can serve as a reference base for a coherent implementation of relevant EU policies and future Ecolabel criteria. Furthermore, it can also support research activities relating to the development of design concepts, common language and relevant technical standards which aims to promote material efficiency in products and the circular economy. Such developments should also aim to quantify the expected impacts from any material efficiency measures set in different policy tools/labels. For any quantitative data, LCA is the key tool to understand potential environmental benefits and associated trade-offs. However, other political, technical and socio-economic considerations also need to be considered to ensure the feasibility of such measures.

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Compliance with ethical standards

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