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Ten years of scientific support for integrating circular economy requirements in the EU ecodesign directive: Overview and lessons learnt

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ABSTRACT

The paper presents and analyses the REAPro Research programme led at the JRC that allowed the Commission to move from the formulation in 2011 of a general policy need to improve circularity of products through design, to the concrete implementation in 2019 of innovative and ambitious circular economy criteria in entry market European legislation. This policy innovation entailed the robust development of complementary components along the policy process, including *policy agenda setting* (better formulation of the policy need), *policy formulation* (e.g. identification of indicators to measure resource efficiency of products), and *policy implementation* (initiation of standardization activities). The paper looks back into 10 years of scientific support to policy and draws some conclusions concerning the needs of scientific support for policy making.

1. Introduction

Design for Environment (DfE) and Ecodesign have been a key topic of research of the Life Cycle Engineering community and many indicators, strategies, methods, tools and approaches have been developed (Duflou et al., 2003; Hauschild et al., 2004).

Policy has always been a key driver of the development of ecodesign both in academia and in the industry. For example, important research work concerned design for recycling of vehicles when the End-of-Life Vehicle Directive (2000) was under preparation; similarly, the imminence of the publication of the Waste Electric and Electronic Equipment Directive in 2002 boosted research in design for recycling of electr(on)ic equipment; when the Ecodesign Directive (2005) was under discussion, the academic community concentrated on energy efficiency through design (see e.g. (Domingo et al., 2012)). Ecodesign Directive had even its keynote speech during the LCE Conference 2006.

With the implementation of the Circular Economy Action Plan (European Commission 2015) since 2015, the European Union has a strong agenda concerning resource efficiency. This includes the willingness to impose on certain product groups some minimum (but still ambitious) requirements concerning circular economy, in particular through entry market instruments such as the Ecodesign Directive. Such requirements could concern reparability, durability or recyclability of products. To be enforceable in the context of entry market instruments, such requirements need to also be verifiable, e.g. through standardised methods.

This paper summarizes and analyses the scientific research programme called REAPro "Resource Efficiency Assessment of PROducts" led by the Joint Research Centre (JRC), which was essential to allow the European Commission to move from the formulation of general policy objectives to the implementation of innovative, ambitious and measurable circular economy requirements in the European entry market legislation. The REAPro Research Programme has been carried by the JRC, the Knowledge centre of the European Commission, and has mainly supported the policy work of DG ENV, DG GROW and DG ENER. This long-standing policy support started in 2009 with an exploratory project for the conception and formulation of exemplary criteria, and it was successfully concluded with the publication in 2019 of the Commission Regulation (EU) 2019/424 concerning Ecodesign of Enterprise Servers. This "journey" entailed the development of several complementary and necessary components. This paper summarizes these developments and explains and discusses what have been the necessary scientific and technical breakthroughs that turned this achievement possible. Following a brief description of the policy context (Section 2), Section 3 describes the main components brought

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Table 1
Circular economy requirements contained in the Ecodesign regulation (2019/424) for enterprise servers (adapted from (Polverini et al., 2018)).

Product Requirement	Content and formulation
Design for disassembly of key components	The following types of components (when present) shall be identified, accessible and removable by hand or with commonly available tools: (a) HDDs and/or solid state devices (b) memory, (c) processor)(d) motherboard, (e) expansion cards/graphic cards, g) power supply
Mandatory declaration of critical raw materials	Indicative weight range at component level, of the following critical raw materials Cobalt (in the batteries) and Neodymium (in the HDDs) should be given in product information
Secure Data deletion built-in function	Secure data deletion of potentially reusable data storage devices (i.e. HDDs, SSDs, memory cards) shall be ensured by providing a data deletion function with the product
Availability of firmware updates to reuse operators	The latest version of firmware for the enterprise server/data storage product shall be made available to third parties dealing with maintenance, reuse and upgrading of servers

Table 2
Summary of circular economy features of Ecodesign regulations published in October 2019.

Product group	Main circular Economy Features
Electronic displays (Regulation C(2019) 2122 final)	Dismantlability; marking of plastic parts; halogenated flame retardant free; labelling of hazardous substances; availability of spare parts and repair information; firmware updates;
Refrigerator (Regulation C(2019) 2120 final)	Availability of certain spare parts and repair information; information for users on waste food
Dishwashers (Regulation C(2019) 2123 final); Washing machines an washers driers (Regulation C(2019) 2124 final); Refrigerating appliances with a direct sales function (Regulation C(2019) 2127 final)	Availability of certain spare parts and repair information, labelling of refrigerant gases (if any)
Welding equipment (Regulation C(2019) 6843 final)	Availability of certain spare parts and repair information, declaration of critical raw materials

by the REAPRo research programme. Following a short discussion (Section 4), main conclusions are given in Section 5

2. Policy context of the REAPro research programme

Addressing life cycle thinking and consumption of natural resources already at design stage has been a policy ambition for several decades, already since the 5th Environmental Programme from 1995 (European Commisison, 1993) and the Community strategy on Integrated Product Policy in 2003 (European Commission, 2003). Since then, the 2003 WEEE Directive and its article 4 on product design has promoted more circular electr(on)ic products (Directive, 2003). In 2005 and in 2009, the Ecodesign Directive has established a framework for the setting of ecodesign requirements for energy-related products, also concerning many environmental aspects including ease for reuse / recycling and lifetime extension (Directive, 2009).

Despite these initiatives, it was still uncertain in 2011 on *how* to do this: the Resource Efficient Flagship then vaguely stated that there was a "*need to find the right policy mix (…) as improving the design of products can both decrease the demand for energy and raw materials and make those products more durable and easier to recycle*" (European Commission, 2011a). Ecodesign Directive had in its first year mainly regulated energy efficiency performances. Still, several regulations had already included circular economy requirements, but they were in general non-binding as they requested general information for end-of-life, using loose formulation like: "*the technical documentation (…) shall contain (…) information relevant for dismantling, (…) recycling, recovery and disposal at end-of-life*" (EC regulation 66/2014 for ovens).

In the Circular Economy Action Plan (2015), product policies are keystones of several sections, including Ecodesign Directive for the production section, and EU Ecolabel for of the consumption section: "*Better design can make products more durable or easier to repair, upgrade, remanufacture [or to recycle].*" This communication also announced the emphasis on circular economy aspects in future product requirements under the Ecodesign Directive, giving the example of electronic displays regulation (European Commission, 2015).

It has been however necessary to wait for 2019 to have such circular economy requirements positively voted by Member States and then adopted: the Ecodesign regulation applied to enterprise servers (EC Regulation 2019/424) that contains not only energy efficiency requirements but also several original, novel and binding circular economy requirements (see Table 1) was published in March 2019.

This first-of-a-kind regulation was then followed on October 1st 2019 by 10 other Ecodesign Regulation[1] (including one on electronic displays containing numerous ambitious circular economy requirements), out of which 6 regulations were containing both energy efficiency and significant resource efficiency provisions (see Table 2). Those circular economy requirements will need now to be implemented by manufacturers' design teams. Compliance with these requirements will be verified by market surveillance authorities of Members States, following procedures defined in recently adopted regulations.

3. Scientific and technical contributions of REAPro research programme

3.1. Setting the policy agenda by defining resource efficiency assessment criteria in a product policy context

While the 2010–2011 policy agenda was still vague (see above), REAPro research programme helped to define better what is actually meant by "resource efficiency of products". Building on existing literature (e.g. (Ardente et al., 2003; Huisman et al., 2003; Mathieux et al., 2008)), but also on existing standards (ISO 14021, 2016), it was possible to identify five relevant criteria for resource efficiency assessments in a product policy context: *reusability/recyclability/recoverability* (by weight and environmental impact), *recycled content* (by weight and environmental impacts) and *content of hazardous substances* (F. Ardente and Mathieux, 2014). An additional original criteria related to *durability assessment*, was also developed later (F. Ardente and Mathieux, 2014; Bobba et al., 2016). Such durability criteria could be related to the reliability of

[1] https://ec.europa.eu/commission/presscorner/detail/en/qanda_19_5889

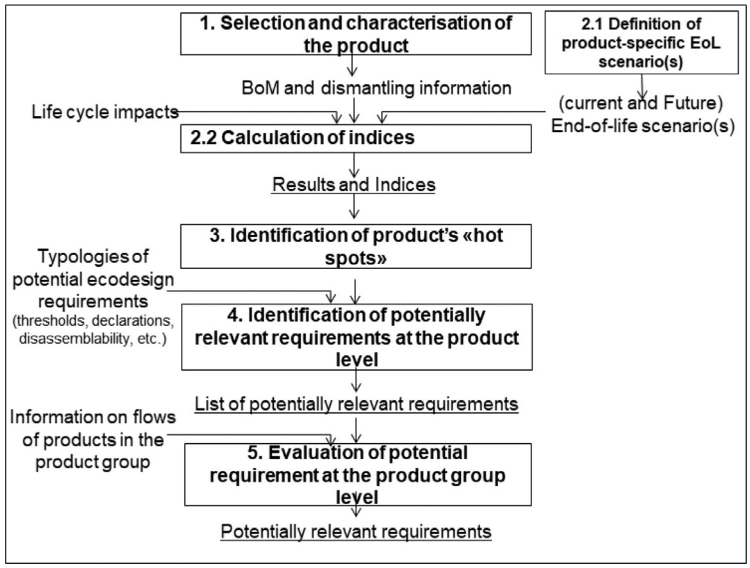

Fig. 1. REAPro overall method aiming at calculating relevant material efficiency indices and deriving relevant product requirements (simplified from (F. Ardente and Mathieux, 2014)).

the product but also to its ability to be repaired, upgraded or even remanufactured.

This agenda was endorsed through the adoption of criteria in follow-up communications (e.g. (European Commission, 2015) and (European Commission, 2011b)) and also of some indicators in the 2013 version of MEErP,[2] the official methodology to be used during Preparatory Study under Ecodesign Directive.

3.2. Suggesting policy formulation

Attached to each of these six assessment criteria, mathematical indicators related to *reusability/recyclability/recoverability* (by weight and environmental impact), *recycled content* (by weight and environmental impact) (F. Ardente and Mathieux, 2014) and *durability* (F. Ardente and Mathieux, 2014; Bobba et al., 2016) as well as associated database (e.g. (Chancerel, 2016) for recyclability assessment) were defined, also building on literature. Along the years, the material efficiency assessment method was then applied to nine product groups, including electronic displays, washing machines, dishwashers, refrigerating appliances with a direct sales function, enterprise servers, laptops and vacuum cleaners, to support policy discussions. To do so, and to run recyclability calculations, it has been also necessary to define typical and representative European values of recycling rates of materials contained in specific products. For example, typical value of recycling rates of materials contained in laptops and washing machines were presented in coordination with academia in (Chancerel, 2016).

An integrated method on how to run material efficiency assessments on product groups (including setting of relevant recovery scenarios), and how to link them with product characteristics (i.e. "hot spots" and potential policy measures), associated to potential impacts and benefits, was also proposed (see Fig. 1). This integration of indicators in the existing policy process, and the coupling with the MEErP methodology was then validated through its use in several real policy processes. The novel approach to "operationalize" circular economy principles all along the policy process of Ecodesign Directive is presented in length in a recent article dealing with enterprise servers (Talens Peiró, 2020). It includes interventions at all stages of the policy process, from early stages (e.g. analysis of current resource efficiency performances of the product group involving end-of-life operators) to late stage (including indicators for impact assessment, before legislative adoption, and initiation of standardization activities). Two critical steps of the process in Fig. 1 concern step 3 when resource efficiency assessment results are associated to product "hot spots" (e.g. durability assessment could show the potential benefits to extend the lifetime of the product) and step 4 when "hot spots" are associated to potential policy requirements (e.g. lifetime extension could be linked to availability of spare parts).

Policy formulation also required to be creative for the development of minimum requirements for mandatory regulation: it was necessary to go away from general loose formulation (see above) and find more binding - and still verifiable - requirements. The challenge of appropriate and verifiable requirements was even greater in the (temporary) absence of standards. An example of formulation is the one developed for enterprise server (see Table 1) where "*manufacturers shall ensure that joining, fastening or sealing techniques do not prevent the disassembly for repair or reuse purposes*" of eight typical components. Such requirement is binding as it can be verified by Market Surveillance authorities of Member States thanks to compulsory information also required to manufacturers concerning "*instructions on the disassembly operations (…), including, for each necessary operation and component: (a) the type of operation; (b) the type and number of fastening technique(s) to be unlocked; (c) the tool(s) required*" (EC Regulation 2019/424). In the future, more quantitative (and verifiable) approaches to measure ease of dismantling performances will have to be found.

Similarly, creativity was needed to develop requirements concerning unexpected topics such as data privacy: during the resource efficiency analysis of enterprise servers, re-use operators gave the feedback that if manufacturers were giving access to data deletion functionalities in the product, re-use activities of some components such as hard drives without risk of personal data leakages could be developed further.

The development of innovative but still verifiable requirements on material efficiency required close cooperation between resource efficiency experts (the voice of recyclers or re-use operators) and policy makers (conscious of verifiability and balancing costs (e.g. administrative burden for manufacturers and member states) and benefits.

[2] https://ec.europa.eu/growth/industry/sustainability/ecodesign_en

3.3. Implementation

A very important component to turn possible the elaboration of binding requirement under Ecodesign regulations are standards (Bundgaard et al., 2017). Standards, that are developed and agreed by industries, often on the request of policy makers, are needed to define agreed metrics to measure (and verify) a resource efficiency performance for a product, especially in policy context. Hence, a group of manufacturers together with NGOs, recyclers, and resource efficiency experts from the JRC have defined a draft mandate to be given to European Standardisation Organisation to develop generic standards related to material efficiency aspects (M/543 Commission implementing decision C(2015)9096). It included topics such as: reusability, recyclability, recoverability, upgradability, durability, reparability, re-manufacturability. These standardisation needs including adequate metrics for performance measurements, reliable and repeatable tests, and calculation procedures, have been presented in details in (Tecchio et al., 2017). The need for standardised method for material efficiency, especially on dismantlability to enhance recycling, was already discussed in an LCE conference in 2014 (Mathieux et al., 2014).

Since then, standardisation activities are on-going and several relevant standards, such as "*General method to declare the use of critical raw materials in energy-related products*" (EN 45,558:2019), "*Methods for providing information relating to material efficiency aspects*" (EN 45,559:2019) and "*General method for assessing the proportion of reused components in energy-related products*" (EN 45,556) have already been published. They will support the future implementation of circular economy aspects under Ecodesign Directive. At the moment, these standards are *horizontal*, meaning that they can be applied to any products. However, upcoming Ecodesign regulations will require that *vertical* product-specific standards will be developed, in particular through adaptation of horizontal standards.

Other standards related to recyclability and ease of reparability are still under development and could very well take inspiration of works of the CIRP LCE community (e.g. (Vanegas et al., 2018)).

3.4. Summary

In summary, in order to make possible the adoption of ambitious and verifiable circular economy requirements under Ecodesign Directive, it was not only necessary to take inspiration from existing scientific literature on Design for Recycling, but it was also necessary to develop new indicators and to use (and sometimes develop) EU representative datasets to run these indicators. It was also necessary to create and "engineer" innovative formulations for requirements that could be verified by Market Surveillance Authorities despite the current absence of standards. It was also necessary to initiate and contribute to standardization development, either by defining the needs or by suggesting potential standardized methods (see e.g. (Vanegas et al., 2018; Recchioni et al., 2015)). Finally, to complete the policy cycle, it was necessary to adapt REAPro indicators to also support the formal "impact assessment" before the final adoption of EU legislation (see e.g. (Talens Peiró, 2020)).

This is summarized in Fig. 2.

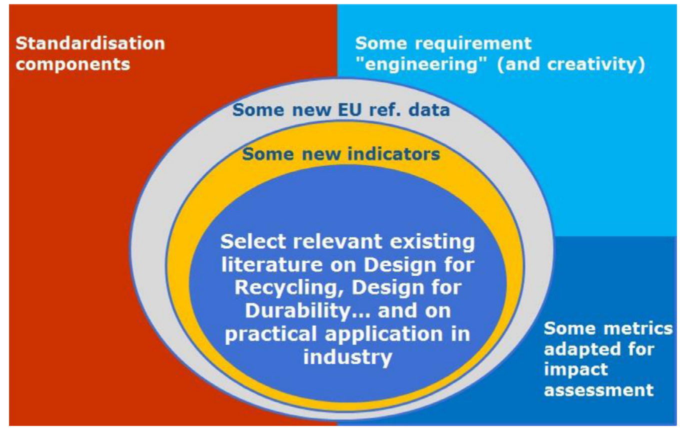

Fig. 2. Overview of all the components of REAPRo research programme that turned possible the definition of mandatory circular economy requirements under Ecodesign Directive.

4. Discussions and lessons learnt

4.1. Contribution of research organizations

Although the JRC was the best positioned (both well aware of latest scientific and technical developments and close enough to policy making process to understand the needs), to develop the necessary components, REAPro research programme benefited a lot from inputs from academia. Academia not only helped for carrying out resource efficiency assessment for specific product groups (see study on laptops (Tecchio et al., 2018)), but has also brought fresh ideas to develop basis for standardization methods, for example for verifiable disassemblability metrics (Vanegas et al., 2018). Academia also rigorously developed basis of database for reference recycling rates data to support recyclability calculations (see e.g. (Chancerel, 2016)).

The approach of the JRC to publish in scientific journals each and every component of the REAPRo method, also with academia, brought more robustness in the whole exercise. Scientific publications were also useful in the policy process: a credible scientific basis for the policy discussions had been created and it contributed to overcome the initial diffidence of some stakeholders.

Academic colleagues from Linkoping, Aalborg and Lund universities also helped the JRC to organize a workshop on the topic. Bringing together a few manufacturers, policy makers, NGOs and recyclers in a scientific conference (GCPSC 2015 in Barcelona) disconnected from any specific policy file helped triggering constructive discussions and building some consensus on the subject.

Currently, several academic colleagues (including members of the CIRP LCE community) are representing their countries and are actively involved in standardization activities in the area at CEN/CENELEC.

Inversely, the REAPro work did also contribute to create a real scientific community dealing with scientific development to support EU product policy (see e.g. (Bundgaard et al., 2017; Vanegas et al., 2018; Hinchliffe and Akkerman, 2017)).

4.2. Interactions with stakeholders

Because integrating circular economy in EU entry market legislation touches several policies, including single market, energy and resource efficiency policies, several policy DGs such as ENV, GROW and ENER of the European Commission were involved. JRC had an important role of consensus building amongst these DGs, showing for example that circular economy requirements were not detrimental to energy efficiency and that they were verifiable by Market Surveillance Authorities of Member States. The scientific and technical support of the JRC was very important all along the process, from the agenda setting until the fine-tuning of the regulations. The first period (2010–2014) was invested to demonstrate policy DGs on the feasibility and relevance of having resource efficiency requirements into Ecodesign policy; the remaining time was invested to pave the road for the development and implementation of such requirements in the legislation. Building the trust with policy officers along the years was extremely important. By developing novel scientific methods and evidences fit for real policy processes, JRC played its role of building bridges between the research community and policymaking. Interactions with market surveillance authorities of Member States were also extremely important to select and fine-tune workable circular economy requirements, as discussed in (Talens Peiró, 2020).

Key stakeholders in the context of the Ecodesign Directive are obviously product manufacturers and importers, often represented by business / trade associations. Although this kind of stakeholders was not always supportive to ambitious circular economy requirements in entry market legislation, their inputs during the policy process were valuable to ensure that requirements were not excessively burdensome for them (see e.g. (Talens Peiró, 2020)). Once they have understood that they could probably not escape from mandatory circular economy requirements under EU legislation for their products, manufacturers have been extremely pro-active for the definition of standards to measure material efficiency performances, as for example reported in (Tecchio et al., 2017).

Finally, besides involving NGOs (see e.g. (Tecchio et al., 2017)), it was extremely important during this policy innovation to systematically involve end-of-life operators in the process, both by collecting data at their premises or through interviews (Ardente et al., 2015) and by having them in formal consultation meetings (Talens Peiró, 2020).

4.3. Limitations of the approach

Although the development of circular economy requirements in the context of the Ecodesign Directive has been here presented as a fluid and rather straightforward process, reality was actually very different. As pointed out in introduction, the journey from the general policy formulation to a specific regulation took almost 10 years. Many delays were experienced due to technical, legal and policy discussions. Several parallel policy processes on various product groups and different stakeholders were actually necessary to obtain tangible results.

Another limitation is that the least preferable material efficiency option, i.e. recyclability, has been often targeted by these research and policy efforts, instead of e.g. durability. This can be explained by several factors. First, at the start of the decade, recyclability assessment was a much better defined concept than e.g. reusability as standards and associated database were already existing: it was therefore easier to assess recyclability, identify improvement opportunities and ways to verify these features on products. Second, the REAPro method, building on published methods, had proposed to consider relevant end-of-life scenarios (F. Ardente and Mathieux, 2014), i.e. scenarios representative of the situation in Europe when the products would reach their end-of-life. Recycling being currently a much more deployed scenario in Europe compared to re-use or re-manufacturing, it is not a surprise if recyclability scenarios assessments and criteria were initially preferred to re-usability or durability ones. Recent improvements need however to be highlighted: six Ecodesign regulations published in 2019 actually provisions on reparability and extension of lifetime (see Table 2). Situation should continue to improve in this regards as several technical committees of CEN/CENELEC are currently developing standards related to preferred options, such as re-usability, reparability, durability and re-manufacturability (Tecchio et al., 2017).

Although innovative, the circular economy requirements adopted in several 2019 regulations and described in this paper certainly do not represent the panacea: for example, several requirements are verifiable only through documentation and not through measurement while some aspects such as availability of spare parts are Boolean parameters (yes/no) while reality is definitely a bit more fuzzy (are spare parts *easily* available, and at which *cost*?). Moreover, complying with those entry-market requirements does not guarantee that the products will have positive effects on re-use and recycling systems at end of life. Still, by their mandatory nature, those requirements represent a major breakthrough and it is expected that the level of ambition, the verifiability and the real impact on circular economy will be slowly improved with regular reviews of regulations, experience and elaboration of standards.

Still, considerations of circular economy in future Ecodesign regulations are not yet guaranteed and they will depend on the active involvement of material efficiency experts and relevant stakeholders (e.g. recyclers, re-use operators) in the preparatory work, as well explained in Talens Peiró et al. (Talens Peiró, 2020).

The technical and scientific methods and indicator developed in the context of this research programme were a pre-requisite to any adoption of circular economy requirements under Ecodesign Directive. But they were not the only necessary conditions to such achievements and political (from DGs of the European Commission, from key Member States) and social (from NGOs, from end-of-life operators, from pro-active manufacturers) supports were actually necessary to obtain positive votes of Member States. The role of stakeholders in the adoption of the enterprise servers regulation is discussed in depth in the paper (Talens Peiró, 2020).

Obviously, the circular economy requirements discussed in this paper will not alone allow the EU to implement a circular economy: the production stage and ecodesign requirements are included in only one of six chapters of the 6 chapters of the 2015 Circular Economy Action Plan (European Commission 2015); many more actions on consumption, on use, on waste management, closing the loop from waste to resources and research & innovation will be needed. Moreover, the set-up of a circular economy will clearly require fundamental changes in the way of producing and consuming products and services. Authors hope that the methods and novel requirements presented in this paper will (even modestly) contribute to these expected economy and policy shifts. When the production and consumption systems will have dramatically changed, the methods, indicators, scenarios and underlying data will anyway have to evolve to integrate new parameters.

4.4. Lessons learnt

The following main lessons can be drawn from this long scientific and technical policy support:

1 *It is possible to regulate a large variety of circular economy aspects through entry market legislation*: this exercise does not only rely on novel and adapted indicators, data and methods, but also on their smooth integration along the policy process with the right stakeholders;
2 This innovative process was only possible thanks to the set-up of a *secure and long-standing climate between many stakeholders*, including resource efficiency experts, policy makers, manufacturers, recyclers, and market surveillance authorities;
3 Although the work of JRC during this policy innovation was mainly to support and adapt the policy process and tools, *systematic publication in scientific journals* of each components of the methods and approaches was extremely instrumental, both to increase robustness of the work (and hence reduce diffidence of stakeholders) and to engage academic partners in the work.

5. Conclusions and outlook

This paper has presented the necessary scientific, technical and organization components that have been put together to realize a major breakthrough in circular economy policy, i.e. to enforce ambitious and binding resource efficiency requirements for products to be put on the EU market. These components, including criteria, indicators, methods, “requirements engineering" and initiation of standardization work have been illustrated on a few product groups. Smooth integration of those components along the policy process with the relevant stakeholders has also been illustrated. Of course, enforcing even more ambitious material efficiency requirements on durability, repair, and recycling will be easier when a full set of horizontal standards will be available.

Now that policy makers have the toolbox to give more emphasis on circular economy aspects in future product requirements under the Ecodesign Directive, as requested by the Circular Economy Action Plan, and because circular economy is at the heart of the new Commission agenda, it is likely that manufacturers will invest more in design for Circular Economy activities. It is also likely that, after several years of relative lower activity in the area of ecodesign, academia will be asked to develop innovative methods and solutions to turn products more circular, still in line with legislative provisions. This expected renewed research activity will be measurable only in a few years. Moreover, it will only be in a few years that it will be possible to verify whether these legislative provisions, with all their strengths but also limitations (limited number of criteria, limited coverage due to verifiability, etc.), have indeed achieved their initial objectives: cut all non-circular products from the market and incentivize the development of more circular and innovative products. Academia is invited to already set-up monitoring tools and studies in this area.

Now that integration of preliminary circular economy requirements concerning re-use / repair and recycling have been enforced in EU legislation, it is time to explore whether perceived higher level of circularity (e.g. remanufacturing, see (Bobba et al., 2020)) and new business models (e.g. leasing, see (Sakao et al., 2019)) could effectively turn the economy more circular, and if this is the case, how EU policy could effectively support their developments.

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References

Ardente, F., Beccali, G., Cellura, M., 2003. Eco-suistainable energy and environmental strategies in design for recycling: the software ENDLESS. Ecol. Model. 163 (1–2), 101–118.
Ardente, F., Calero Pastor, M., Mathieux, F., Talens Peiró, L., 2015. Analysis of end-of-life treatments of commercial refrigerating appliances: bridging product and waste policies. Res. Conserv. Recycl. 101, 42–52.
Ardente, F., Mathieux, F., 2014. Environmental assessment of the durability of energy-using products:method and application. J. Clean. Prod. 74, 62–73.
Ardente, F., Mathieux, F., 2014. Identification and assessment of product's measures to improve resource efficiency: the case-study of an Energy using Product. J. Clean. Prod. 83, 126–141.
Bobba, S., Tecchio, P., Ardente, F., Mathieux, F., Marques dos Santos, F., Pekar, F., 2020. Analysing the contribution of automotive remanufacturing to the circularity of materials. In: Submitted to the CIRP LCE Conference.
Bobba, Silvia, Ardente, Fulvio, Mathieux, Fabrice, 2016. Environmental and economic assessment of durability of energy-using products: method and application to a case-study vacuum cleaner. J. Clean. Prod. 137, 762–776.
Bundgaard, A.M., Mosgaard, M.A., Remmen, A., 2017. From energy efficiency towards resource efficiency within the ecodesign directive. J. Clean. Prod. 144, 358–374. http://dx.doi.org/10.1016/j.jclepro.2016.12.144.
Chancerel, P., et al., 2016. JRC Report.
Directive, 2003. On Waste Electrical and Electronic Equipment (WEEE).
Directive, 2009. Establishing a Framework For the Setting of Ecodesign Requirements For Energy-Related Products.
Domingo, L., Mathieux, F., Brissaud, D., 2012. A new In-Use Energy consumption indicator for the design of energy efficient electr(on)ics. J. Eng. Design 23 (1–3), 217–235.
Duflou, J., Dewulf, W., Sas, P., Vanherck, P., 2003. Pro-active Life Cycle Engineering Support Tools. CIRP Annals 52 (1), 29–32.
European Commisison, 1993. Towards sustainability. In: 5th European Community Programme of policy and action in relation to the environment and sustainable development.
European Commission, 2003. Community strategy on integrated product policy, building on environmental life-cycle thinking. COM 302.
European Commission, 2011a. A resource-efficient europe – flagship initiative under the Europe 2020 strategy. COM 571.
European Commission, 2011b. Roadmap to a resource efficient europe. COM 21 final.
European Commission, 2015. Closing the loop - An EU action plan for the Circular Economy. COM 614 final.
Hauschild, M.Z., Jeswiet, J., Alting, L., 2004. Design for environment — do we get the focus right? CIRP Annals 53 (1), 1–4.
Hinchliffe, D., Akkerman, F., 2017. Assessing the review process of EU Ecodesign regulations. J. Clean. Prod. 168, 1603–1613.
Huisman, J., Boks, C.B., Stevels, A.L.N., 2003. Quotes for environmentally weighted recyclability (QWERTY): concept of describing product recyclability in terms of environmental value. Int. J. Prod. Res. 41 (16), 3649–3665.
ISO 14021, 2016. Environmental Labels and Declarations — Self-declared environmental Claims.
Mathieux, F., Froelich, D., Moszkowicz, P., 2008. "ReSICLED: a new Recovery Conscious Design method for complex products based on a multicriteria assessment of the recoverability. J. Clean. Prod. 16 (3), 277–298.
Mathieux, F., Recchioni, M., Ardente, F., 2014. Measuring the time for extracting components in end-of-life products: needs for a standardized method and aspects to be considered. Proc. CIRP 15, 245–250.
Polverini, D., et al., 2018. Resource efficiency, privacy and security by design: a first experience on enterprise servers and data storage products triggered by a policy process. Comput. Secur. 76, 295–310.
Recchioni, M., Ardente, F., Mathieux, F., 2015. JRC Technical report ISBN: 978-92-79-33276-0.
Sakao, T., Wasserbaur, R., Mathieux, F., 2019. A methodological approach for manufacturers to enhance value-in-use of service-based offerings considering three dimensions of sustainability. CIRP Ann. - Manuf. Technol. 68, 33–36.
Talens Peiró, L., et al., 2020. Advances towards circular economy policies in the EU: the new Ecodesign regulation of enterprise servers. Res. Conserv. Recycl.. https://doi.org/10.1016/j.resconrec.2019.104426.
Tecchio, P., et al., 2017. In search of standards to support circularity in product policies: a systematic approach. J. Clean. Prod. 168, 1533–1546.
Tecchio, P., Ardente, F., Marwede, M., Christian, C., Dimitrova, G., Mathieux, F., 2018. Analysis of material efficiency aspects of personal computers product group. EUR 28394 EN, Luxembourg doi:10.2788/89220, ISBN 978-92-79-64943-1.
Vanegas, P., et al., 2018. Ease of disassembly of products to support circular economy strategies, Resources. Conserv. Recycl. 135, 323–334.