Potential Greenhouse Gas Emissions Reduction from applying Circular Economy Principles to Ecodesign Products

An exploratory study to quantify the potential impacts on GHG emissions from applying principles of the Circular Economy to Energy related Products in Europe

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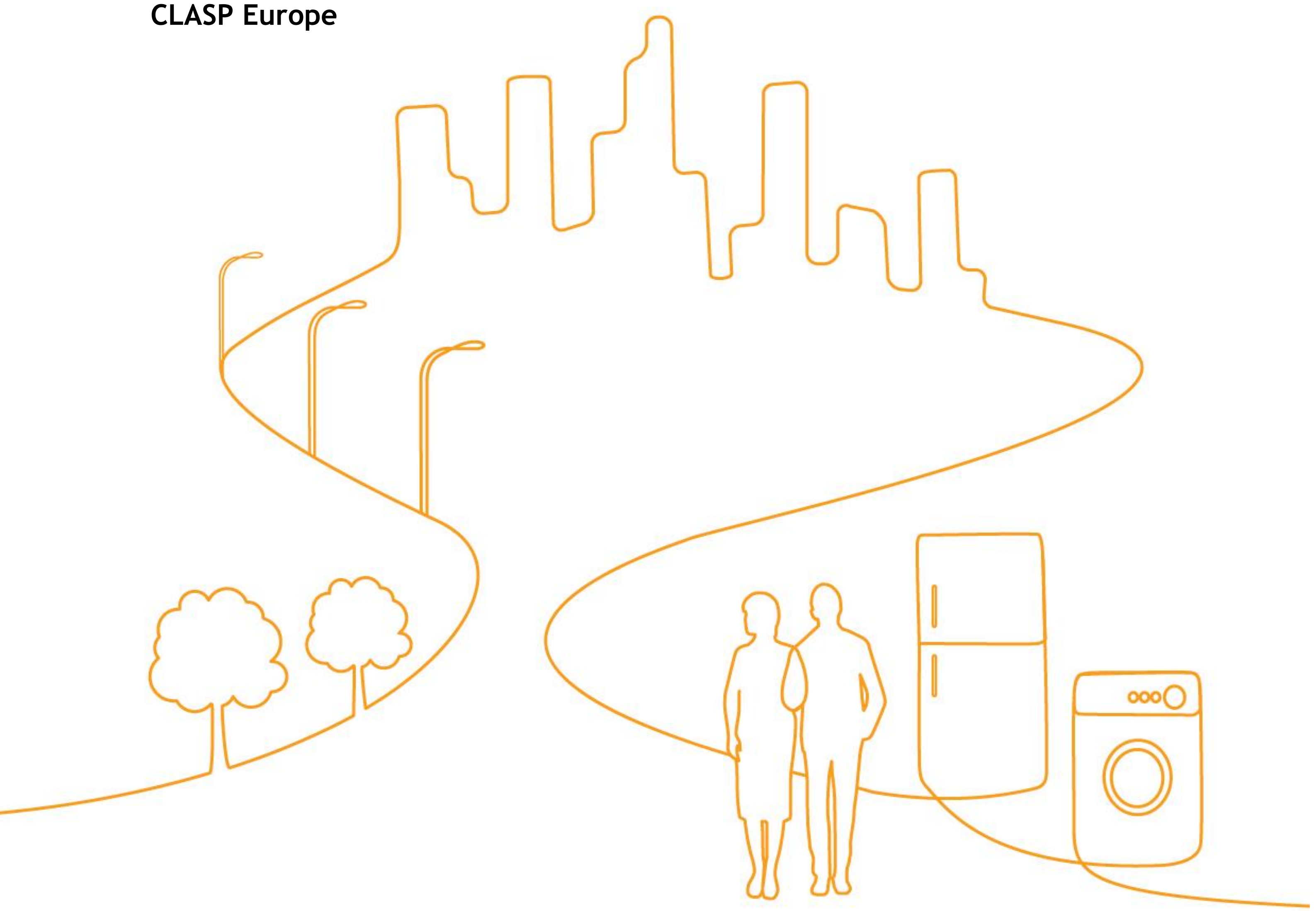
CLASP Europe



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About CLASP

An independent, non-profit organisation, CLASP improves the environmental and energy performance of the appliances and related systems we use every day, lessening their impacts on people and the world around us. CLASP develops and shares practical and transformative policy and market solutions in collaboration with global experts and local stakeholders. We are the leading international resource and voice for energy efficiency standards and labels (S&L) for appliances, lighting, and equipment. Since 1999, CLASP has worked in over 50 countries on 6 continents pursuing every aspect of appliance energy efficiency, from helping structure new policies to evaluating existing programs. Please visit www.clasp.ngo

Executive summary

ES.1 Objective of the Study

The European Commission recently adopted an ambitious Circular Economy Package which included a legislative proposal on waste designed to stimulate Europe's transition towards a circular economy.[1] A circular economy is described in this document as an economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised". The Commission anticipates that this transition would boost global competitiveness, foster sustainable economic growth and generate new jobs. With an interest in improving the general understanding of the greenhouse gas emission impact of such a transition, this short exploratory study was designed to provide first-order estimates of the greenhouse gas emission reductions that could be expected from energy related products (ErP) covered by the European Union (EU) Ecodesign and Energy Labelling regulations.

The study looks into all stages of the product life cycle to assess and quantify the additional emissions reductions that could be delivered by applying the principles of a circular economy in Europe. These estimates are intended to provide guidance on where policy action promoting circular economy principles should focus in order to mitigate greenhouse gas emissions.

ES.2 Methodology

At the moment there are more than 30 product groups (also called product "Lots") which are regulated under the EU Ecodesign and Energy Labelling directives. These 30 product groups were divided into five product categories, and a representative product was selected from each product category for analysis. The findings calculated for the representative product were then extrapolated to all the other products within the product category where individual analysis per product was not possible.

As stated above, this study is exploratory in nature and is meant to provide first-order estimates of the range of possible circular economy impacts on greenhouse gas emissions. Limitations had to be established concerning the scope and depth of analysis of the study. These limitations include:

- Environmental impacts assessed - only CO_2 emissions impacts were analysed in this study, although other environmental impacts would deserve a similar analysis;
- Analysis boundaries - the whole life cycle of the products analysed was covered in this study, from extraction of materials through to disposal; however impacts beyond the product boundary (e.g., factory retooling and exogenous infrastructure upgrades) were considered outside of scope;

[1] Closing the loop - An EU action plan for the Circular Economy, COM(2015) 614 final, 2.12.2015; http://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

- Technological obsolescence - some aspects of the “smartness” and rapid evolution of products are expected to have impacts on energy in use as well as useful service life. However, this impact was not assessed in this study because forecasting the interplay between technology evolution and consumer demand would be very complex and difficult to predict at this stage, and thus was considered outside of scope.
- Deep design re-think – strong policy and/or price incentives to extend the lifetime of products and/or make them more easy to maintain, refurbish, dismantle or recycle could deeply impact the product design. However, this impact was not assessed in this study because forecasting this type of hypothetical future evolution is impossible at this stage.

The focus of this study is to quantify additional potential greenhouse gas emissions reductions, rather than the specific policy measures that would achieve these. The focus of the calculations is on the kg CO_2-eq. impacts, based on data sources of EC studies, including primarily Ecodesign preparatory studies. This may mean that the impact on CO_2 emissions of material considerations may be under-represented (a sensitivity analysis addresses this in Annex N).

The dozens of energy using products covered under the ecodesign and energy labelling directives were divided into five product categories:

- White goods and related products;
- Lighting products;
- Consumer electronics and related products;
- Motors and motor systems; and
- Heating and cooling products.

In addition, windows, which is an energy-related product (i.e., not an energy using product) was the subject of a specific analysis within the scope of this study.

The aforementioned study limitations notwithstanding, this study estimated the potential CO_2-eq. emissions reductions by product category that could be delivered through a range of different approaches, including:

- Improved recyclability;
- Extended service life;
- Service economy approach (lease, pay-per-unit-of-service, etc.); and
- Improved refurbishment (modelled as one of the scenarios under “service economy approach”).

Improved recyclability represents the impact of increasing the proportion of materials recycled for the expected share of products recycled in 2020, holding product material composition constant. It was assessed on the basis of a literature review focusing on the representative product for each of the five product categories.

Extended service life refers to extending the average lifetime of products. It was assessed by applying the durability methodology in "*Integration of resource efficiency and waste management criteria in European product policies – Second phase – Report n° 1 Analysis of Durability*" [JRC, 2012a].

Service economy approach refers to a market offering based on a new economic model that charges for the service provided by a product, rather than on ownership of physical product itself. It was assessed by modelling the impact of both a "limited adoption" and a "broad adoption" scenario, as described in Table ES.1. The default scenarios presented here were adapted for some products as suggested by literature and product experts.

Improved refurbishment corresponds to one of the scenarios modelled to assess the impacts of a service economy approach.

Table ES.1. Summary of default assumptions under each "service economy" scenario in 2020

Factor	Limited Adoption Scenario (LA)	Broad Adoption Scenario (BA)	Improved refurbishment / Average efficiency Scenario (IR-BA)
Market adoption rate	10%	50%	
Impact of refurbishment and maintenance	One repair/refurbishing/upgrading transaction would take place every five (5) years during the life of the leased machine, each equivalent to 10% of the kg CO_2-eq. impact of initial production.[2]		
Lifetime	The average lifetime of a leased product is assumed to be 1.5 times longer than the average non-leased product.		
Efficiency	Leased products are assumed to be more efficient than the average non-leased product (varies by product)		Same efficiency as average non-leased product.
Impact of a better design[3] for dismantling, repair and recycling (due to leasing influence)	0%	A 20% reduction in the impacts of the extraction of material and of the end-of-life for the base case (due to reduced time and energy required for part/material extraction, to higher recycling rates and even potential re-use of some components).	

In this study we consider the potential impact of applying the principles of a circular economy to the products sold in 2020. For each product, potential emission reductions are calculated for the lifetime of the baseline functional unit.

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[2] The impact of each transaction used to estimate the impact of extended service life is 10% of the initial impact of production and end-of-life. This impact was made quite significant here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport.

[3] Better design for dismantling may also result in increased recycling yields (more material recycled in general, and more recyclable materials present in the original design) but this has not been quantified because it would require changes to the underpinning LCA analyses used in this study and is not predictable. Thus, the estimates presented in this report may be underreporting the benefits.

ES.3 Findings

Of the five product categories studied, consumer electronics emerged as the one for which the potential additional reduction is the highest, particularly for recyclability and extended service life. Concerning the effect of a service economy approach, for many of the analysed products, the average efficiency of the leased products was the most important parameter influencing the potential emissions reduction. This was found not to be the case for many consumer electronics products which have already been addressed by ecodesign requirements improving energy-efficiency for a number of years. For these products, electricity consumption in the use phase may no longer represent such a dominant source of CO_2-eq. emissions over the product life cycle.

In the modelled scenarios, the development of a service economy was linked to the assumption that procurers of leased products would specify products more efficient than the average (purchasing the best quality/performance products on the market). Although anecdotal evidence suggests this assumption reflects the current situation, there is no guarantee that this trend would continue if there was a widespread market shift from the current product-based economy to a service-based economy. Promoting the service economy option then, in the absence of policy measures that would encourage leased products to be more energy-efficient, represents a risk that CO_2-eq. savings related to leasing may not be realised, or even that leasing could increase CO_2-eq. emissions.

One option would be to combine requirements on energy performance and extended life time (*e.g.* via the eco-design and energy labelling regulations), such that the more efficient a product is, the longer it will last. The fact that ecodesign and energy labelling requirements only apply to a product when it is first placed on the market in Europe is appropriate for the current business model (*i.e.* product sales economy), but it may need to be revised if a service-based economy becomes main-stream. For example, under a service-based economy, products will be refurbished (or not) and placed again on the market with greater frequency; and operating software will be updated which could affect product performance and efficiency.

ES.3.1 Findings of the circular economy impacts for white goods and related products

For white goods and related products, the development of a **service economy** approach offers the highest CO_2-eq. reduction potential of the circular economy scenarios assessed for this group, with the modelled impacts of this approach (broad adoption) being approximately 17 Mt CO_2-eq savings for products sold in 2020. This corresponds to around 40-50% of the estimated impact of the ecodesign and energy labelling regulations for these products in 2020. The highest CO_2-eq. emission reduction is achieved by combining this service economy approach with leased products that have a higher efficiency than the average products sold.

The impact of **extended service life** varies significantly between products, depending on the share of the use stage in the total CO_2-eq. emissions and the expected efficiency improvement of the replacement products. Although this is bound to change as improvements in efficiency from new products diminish over time, for most of the products considered in white goods and related products the CO_2-eq. impact of extended service life still tends to result in a slight increase in the total CO_2-eq. emissions.

Based on currently available data applicable to this analysis, the impact of improved **recyclability** on the total CO_2-eq. emissions associated with this product category typically represents less than 1% of the impact of ecodesign and energy labelling measures. Therefore, from the narrow perspective of greenhouse gas emissions (CO_2 eq. emission impacts), improved recyclability does not currently represent an interesting circular economy intervention mechanism – although it has benefits to other environmental impact measures that would make it an appropriate option.

ES.3.2 Findings of the circular economy impacts for lighting products

The impact of the **service economy** approach on lighting products offers a significant reduction of between a 17% (low adoption scenario) and 32% (broad adoption scenario) of the CO_2-eq. emissions reduction due to all of the ecodesign implementing measures for lighting. Thus, the service economy was recognised as offering the best circular economy option analysed for lighting products in this study.

The lifetime of the baseline LED lamps is already long and balanced against the increasing efficiency of new products entering the market, the CO_2 eq. emissions impact of **extended service life** could yield a reduction in existing CO_2-eq. emissions of approximately 1 to 3%. A slight increase in the expected pace of efficiency improvement could cancel this potential reduction and even mean that extending the service life of light sources could result in slightly higher CO_2-eq. emissions due to the dominance of the use phase.

The impact of improving the **recyclability** of LED lighting products is estimated to have a very slight increase in CO_2-eq. emissions relative to the baseline. This increase is due to the energy involved in recovering and recycling the materials embodied in the LED lighting products. Thus, from purely a greenhouse gas emissions perspective, recycling does not appear an attractive policy option, however it could become an appropriate option for CO_2-eq. emissions reductions in the future once the difference in efficiency between existing and new products starts to narrow.

ES.3.3 Findings of the circular economy impacts for consumer electronics and related products

For consumer electronics, our analysis found that **extending the service life** represents the most promising application of the circular economy principles. A clear case can be made for extending the lifetime, with our calculations finding a reduction potential for computers that would be one order of magnitude larger than the reduction estimated from its Ecodesign regulation.

The development of a **service economy** and an **improved recyclability** would also represent interesting options to lower the total CO_2 emissions associated to the life cycle of these products, although the modelled potential of increasing the lifetime appears to be one order of magnitude higher. For televisions, personal computers and imaging equipment, improved recyclability as modelled for this study represents a CO_2-eq. emissions reduction of between 20% and 50% of the savings delivered by their respective ecodesign and energy labelling regulations.

ES.3.4 Findings of the circular economy impacts for motors and motor systems

Even with the energy efficiency improvements achieved for these products over the years, the use phase still dominates the life cycle CO_2-eq. equivalent impacts of motors and motor systems. With the exception of the **service economy** approach, circular economy options that would only affect the production and end-of-life phases would have a very limited impact on the greenhouse gas emissions associated with these products.

The only circular economy option considered in this study that would deliver significant CO_2-eq. emission reduction for motors and motor systems is the **service economy**. Following this approach, businesses would contract motor services from ESCOs, motor manufacturers or other market players that would optimise the management of motors and motor systems. Our analysis estimates CO_2-eq. emissions savings of between 5% and 25% impact derived from the current ecodesign and energy labelling measures.

In stark contrast to this level of savings, the impact of **extended service life** and **recyclability** on the total CO_2-eq. emissions each represents less than 2% of the impact of ecodesign and energy labelling measures, therefore these options do not appear to be strongly justified from a CO_2-eq. emissions viewpoint.

ES.3.5 Findings of the circular economy impacts for heating and cooling products

A **service economy** approach could be effective for reducing greenhouse gas emissions from room air-conditioners (RAC). The efficiency of the leased product is by far the parameter that has the most significant impact on the potential reduction in the modelled scenarios. The potential for central heating products could also be attractive, but it is strongly dependent on the associated energy efficiency improvement, suggesting that the type of contract proposed by an ESCO or other provider could be a good option.

RAC is the only product of this group for which the potential impact of **extended service life** is large enough to be considered interesting in terms of CO_2-eq. emissions. The potential was found to be approximately half of the size of the impact of the ecodesign and energy labelling regulations.

The estimated potential reduction of **improved recyclability**, although not negligible in absolute terms, is found to be one order of magnitude lower than the potential impact of extending the lifetime. Following the policy action already taken to significantly reduce the impact of refrigerant gases, improving recyclability of heating and cooling products no longer appears as a priority to reduce the CO_2-eq. emissions associated with this product category.

ES.3.6 Findings of the circular economy impacts for windows

Non-energy aspects of the LCA for this energy-related product group were considered, and the potential for application of circular economy principles assessed. However, in both cases it was not possible to identify a meaningful way to derive additional CO_2-eq. emissions reductions from windows. It was therefore concluded that this product group does not currently represent a promising source of additional CO_2-eq. emissions reductions from LCA or circular economy principles. However, future studies on windows may identify new Circular Economy principles or find alternative ones that would capture additional emissions savings from this product group.

Table ES.2 gives an overview of estimated potential additional CO_2-eq. emissions reduction for each type of improvement and product category.

Table ES.2. Overview of estimated potential additional CO_2-eq. emissions reduction by type of improvement and product category for 2020 sales*

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended service life	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with average efficiency for service economy	Estimated impact Ecodesign and energy labelling
Products	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
White Goods and related products	71	1,762	3,138	17,014	3,023	39,600
Consumer electronics and related products	12,632	57,991	2,787	16,027	14,115	60,000
Lighting	-0.41	1,238	6,399	12,365	n.a.	38,822
Motors and Motor Systems	208	1,028	4,991	24,964	1	91,200
Heating and Cooling products	189	1,340	1,148	6,069	716	78,100

* For ecodesign the estimated impacts are given for the stock of products in 2020.
* The estimates shown here for each of the five product categories do not take into account the impact of extended service life for product categories where the impact was found to increase CO_2-eq. emissions.

ES.4 Implementation Options

At a recent study group of circular economy experts,[4] three general implementation themes emerged around which the principles of a circular economy could be promoted in Europe. The three general themes are:

- **Communications** - a positive narrative on the benefits derived from new business models and the redesign of products, targeting a wide range of stakeholders from industry to consumer groups;
- **Regulations** – developing and revising product policy regulations to include circular economy principles and supporting new business opportunities through Ecodesign, Energy Labelling, Extended Producer Responsibility, etc.; and
- **Incentives** – the removal of barriers that slow the uptake of circular economy principles and prevent adoption of new business models

Communications

New marketing and communications approaches would be a core element of a campaign to change how people engage with the circular economy. The study group felt that a new, positive narrative should be developed which is more people-oriented and focused on values, good design and quality. This vision for improving communications could be based around three components: (1) product design, (2) business models, and (3) new business players, including aggregators and innovators.

The study group felt that the wider social benefits should be highlighted, such as local jobs, safety of the people, and so-on. It was suggested that organisations such as consumer groups and health charities may be good vehicles to carry these messages, in part because of their strong constituency.

The group also felt that the circular economy approach would be adopted more easily if clear business cases were developed and communicated to the market. Contrasting this approach with vague appeals to promote circular economy which have focused on environmental sustainability, the group highlighted the fact that in a changed business context, companies will have to adopt a new mind-set and innovate. That degree of change is only realistic when robust business cases are developed and clearly communicated to entrepreneurs and progressive business leaders.

Regulations

From a policy perspective, the leadership in Brussels and at the national level across Europe need to ask themselves 'what type of regulation will send clear signals to the companies and incentivise them to fundamentally change their business models?' Fortunately, there are regulatory mechanisms already in place in Europe which can be applied to help promote the circular economy. The ecodesign directive already takes life-cycle assessment into account, and as quantified in the findings of this study, could be further applied to help deliver additional CO_2 savings and the wider environmental, economic and social benefits described in the literature [EMF, 2015].

[4] The European Climate Foundation convened a focused study group in March 2016 in The Hague to discuss circular economy principles and potential implementation measures. The implementation recommendations of that meeting are summarised in this subsection.

To date, the focus of ecodesign has been energy-in-use, because this has been the area of the impact that offers the greatest opportunity for cost-effective improvement. And now, as efficiency levels increase, other aspects of the product life-cycle become relatively more important, which makes the opportunity for impact through the circular economy even more compelling. In addition to ecodesign, a market-push mechanism, the energy labelling directive helps to pull markets towards more environmentally sustainable products. This mechanism, coupled with extended producer responsibility could be applied to help enhance and extend the impact on products.

At a national level, countries could establish special economic zones, as seen in the Netherlands and in China, as a means of finding which regulatory policies are most effective at stimulating the market and facilitating the transition to the circular economy. Furthermore, the inclusion modulated fees as suggested in article 8a 4(b) of the extended producer responsibility scheme would be a positive step towards promoting better performance and transparency of the various national EPR systems. It would promote reusability and recyclability of individual products/ groups of products might be an extra incentive to improve design for recycling.

Incentives

There are many options available to policy-makers which are not regulatory, but which can be applied to help encourage and slowly / smoothly transition markets towards a circular economy and more eco-effective products. The following list provides a few of these incentive schemes:

- **Green public procurement** – defining the specification of products and services that will be procured by public bodies which incorporate aspects of the circular economy, and potentially giving preference to companies that amend their operating procedures (e.g., the Prorail CO_2 performance scheme whereby companies receive an advantage in procurement procedures if they perform better than their competition on some environmental aspects);
- **Green corporate procurement** – encouraging large corporations to adopt the green public procurement specifications into their own procurement practices (e.g., a kind of "Circular Economy Partners" initiative);
- **Adjusting taxes on resources vs. labour** – some aspects of the service economy such as repair, maintenance and refurbishment of appliances can be more demanding than the current linear dominant model in terms human resources. This is a barrier that makes it more challenging for companies to develop a profitable business model based on services than based on products. Additionally, with mass production of appliances, buying an appliance no longer is as a major investment as it once was – in fact, repairing an old one can be more expensive than buying a new one. Furthermore, with rapid obsolescence, consumers may be worried that they would invest in repairing a machine that may be likely to rapidly fail again. For all these reasons, a tax shift seems essential to moving towards a more circular economy, lowering taxes on labour and increasing taxes on the consumption of non-renewable resources, as recommended by the Club of Rome [Club of Rome, 2015].

- **Tax rebates** – as one of the leading mechanisms of control of any government over businesses operating in its economy, offering tax holidays, tax breaks and other tax incentives to promote Circular Economy practices;
- **Feed-in tariffs** – establishing mechanisms that recognise and directly reward practices such as feed-in tariffs which for example have enabled the development of virtual power plants in Germany through performance guarantees, and which have been instrumental in the success of the Energiesprong model, whereby renovations of social housing include the replacement of all household appliances with the most efficient ones;
- **Green financing mechanisms** – establishing low- or zero-interest financing for companies that need capital in order to develop and implement the business plan (note: this financing mechanism could also include a free circular economy business consulting service);
- **Voluntary labelling schemes** – establish new (or adapt existing) labelling schemes to take into account and reward principles of the circular economy; and
- **University design competitions** – recognising that major change will have to come the next generation of innovators and researchers, establish corporate-sponsored design competitions for products that incorporate the principles of efficiency, repair, reuse and disassembly for recycling (e.g., Xeros bead-based washing machines with order-of-magnitude lower water and energy footprint).

ES.5 Suggestions for next steps

This study found that the estimated magnitude of the emissions reduction potential associated with the application of circular economy principles in some product groups is even higher than the emissions reduction from the ecodesign and energy labelling measures for those same products. This study is, however, only a first order estimate of the emissions reduction opportunity and is intended to support the planning and consideration of potential policy actions. It is also intended to help guide future areas of research around principles of a circular economy. Some suggested ideas for follow-on research in this area are given below:

- **Economic assessment** - an evaluation of the economic requirements and potential impacts of applying the principles of a circular economy broadly across Europe, including e.g., a cost-benefit analysis, return on investment, necessary financing, etc.;
- **Accounting standards** – the development of new financial and accounting standards and metrics that capture the full benefits of energy-efficiency and the circular economy;
- **Product metrics** – the development and improvement of metrics to assess whether a product is eco-effective and eco-efficient or not; enabling companies, governments and consumers to identify eco-efficient products;
- **Plastics recycling industry** – conduct market research and develop policy measures designed to stimulate and support the development of a larger and more robust plastics recycling industry in Europe;
- **Best opportunity focus: products** – conduct a more in depth analysis to explore the improvement potential for specific products which offer the greatest greenhouse gas saving potential, and contribution to the ecodesign work plan;

- **Best opportunity focus**: **improvements** - conduct a more in depth analysis to explore the improvement potential for specific improvements which offer the greatest greenhouse gas saving potential. This could cover a product per product analysis of what lifetime extension would be realistic; investigate the upgrading potential of some products, and their modularity. These options are believed to have very significant potential for consumer electronics in particular;
- **Policy measure study** - a research study on potential and appropriate policy mechanisms to encourage a market transition to a circular economy, looking at incentives as well as voluntary and regulatory policy measures;
- **Focus on energy-related products** - a scoping study for products that are related to energy use (e.g., windows or insulation - non-energy using products); and
- **Shared resources** - an evaluation of the potential savings that could be achieved via policy incentives toward a sharing economy in relation to certain ecodesign products (e.g., super-efficient washing machines and tumble driers, game consoles, printers). The scenarios developed for leasing in this study result in saving estimates that are comparable to what could happen when sharing resources (potentially more efficient products, less production and End-of-Life impacts for a same provision of services). Sharing would however not be possible for all products (not for lighting or for Commercial Refrigeration Equipment, for example). Moreover, very little literature could be found about the potential level of adoption of sharing as opposed to owning, or how many potential owners would share the equipment at the same time. These estimates would have to be very product specific.

In the coming years, the community of stakeholders working on circular economy will continue its work to establish and implement a policy framework that supports the redesign of appliances and promotes the uptake of new business models that capture the full decarbonisation and circularity potential of appliances. On-going research, exchanges with experts and engagement with industry will all help to support the overall objective of establishing a comprehensive circular economy in Europe.

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Acronyms and Abbreviations

BA	broad adoption
BAU	business as usual
CCFL	cold cathode fluorescent lamp
CE	circular economy
CFL	compact fluorescent lamp
CO_2	carbon dioxide
CRT	cathode ray tube
DG ENER	Directorate General – Energy (European Commission)
Eq	equivalent
ErP	Energy related Products
ESCO	energy services company
F-gas	fluorinated-gas
GWP	global warming potential
IJ MFD	ink jet multifunction device
IR-BA	improved refurbishment – broad adoption
JRC	Joint Research Centre (European Commission)
kg	kilogram
kt	kilotonne
LA	limited adoption
LCA	life cycle assessment
LCD	liquid crystal display
LED	light emitting diode
OJEU	Official Journal of the European Union
PCB	printed circuit board
PDP	plasma display panel
PS	preparatory study
PVC	polyvinyl chloride
RAC	Room Air-Conditioning
RoHS	Regulation of Hazardous Substances
t	tonne
TV	television
US DOE	United States Department of Energy
VSD	variable speed drive
WEEE	Waste Electrical and Electronic Equipment

1. Introduction

The European Commission recently adopted an ambitious Circular Economy Package which included a legislative proposal on waste designed to stimulate Europe's transition towards a circular economy. The Commission anticipates that this transition would boost global competitiveness, foster sustainable economic growth and generate new jobs. With an interest in improving our understanding of the greenhouse gas emission impact of such a transition, this study was designed to provide first-order estimates of the greenhouse gas emission reductions that could be expected from energy related products (ErP) covered by the European Union (EU) Ecodesign and Energy Labelling regulations. This study looks into all stages of the product life cycle to assess and quantify the additional emissions reductions that could be delivered by applying the principles of a circular economy in Europe. In this study, data gathered from multiple sources, including European Commission contracted preparatory studies are used to prepare the emissions reduction estimates. These estimates represent theoretical potentials and are intended to provide guidance on where policy action promoting circular economy principles could focus in order to mitigate greenhouse gas emissions. The specific form that potential policy actions could take in order to realise these potential savings is intended to be the subject of future research, therefore the mechanisms and policy tools for the implementation of the circular economy are not explored in this report.

1.1. Circular Economy Overview

> *The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe.*
>
> *- European Commission*
> *Closing the loop*
> *An EU action plan for the Circular Economy*

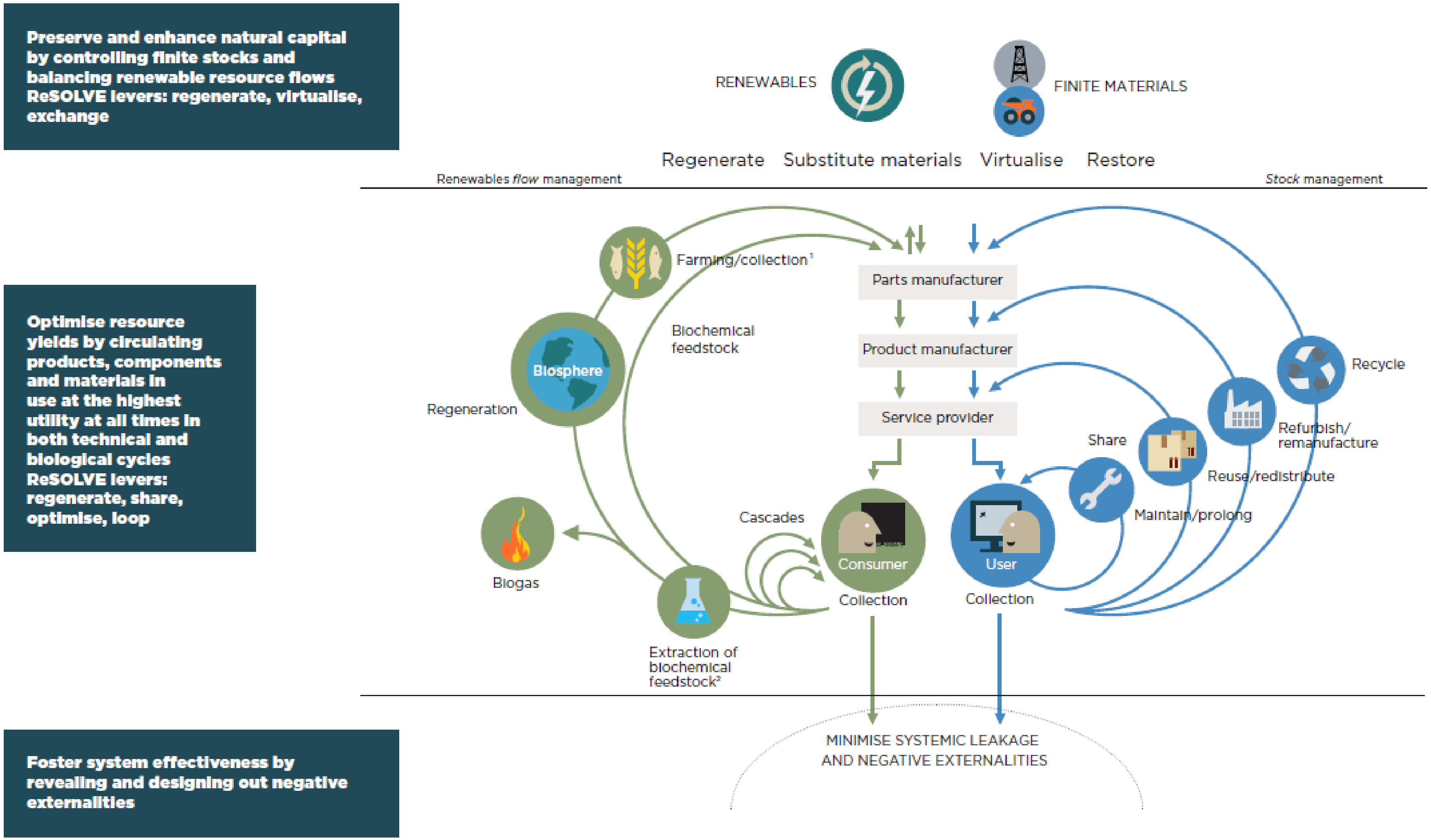
> *A circular economy is restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times.*
>
> *- Ellen MacArthur Foundation*

In other words, a circular economy is a competitive, sustainable economy in which waste is minimised and maximum service value is derived from a given amount of natural resources. The ratio of service to resource is increased through: (1) making products that will offer more units of service[5] per unit of resource, (2) technology improvement and/or (3) longer product lifetime. Once a product fails, components and materials should remain in the system with as little transformation as possible, since

[5] A defined quantity or measure of the service provided by the product or appliance under consideration, such as a kg of clothes washed or a lumen-hour of lighting service.

transformation consumes energy and often results in some portion of the material resources not being reused (i.e., those materials leave the system). A circular economy maximises the ratio of service to resource by applying new market approaches and economic mechanisms to keep products, components and materials at their highest utility and value at all times.

The diagram presented in Figure 1 illustrates the different loops that can be used to restore and regenerate products, components and materials. The circular economy concepts considered in this study are those that impact any of these loops shown in the figure.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
SOURCE: Ellen MacArthur Foundation
Adapted from the Cradle to Cradle Design Protocol by Braungart & McDonough

Figure 1 Circular economy system diagram as depicted by the Ellen MacArthur Foundation

Each loop depicted in the above diagram represents one elementary way to achieve more "circularity". Shorter loops are the most effective at maintaining the highest utility and value of products, components and materials. From the shortest to the largest these loops are:

- Share/maintain/prolong: the product is not affected, or very little through maintenance; the value of materials is maintained and only the relative impact of the use phase increases;
- Reuse/redistribute: from an environmental point of view, the impacts are the same as for share/maintain/prolong: the value of materials is maintained and the relative impact of the use phase increases. In this loop the impact of (re)distribution can increase too, but this impact is generally very minor for the types of product considered here – energy using and energy related products;
- Refurbish/remanufacture: the integrity of the product is affected, some of the value of the material would typically be lost, to various extents. The efficiency in use of the product can be affected.
- Recycle: waste of material is avoided but more value is lost than in the shorter loops, and the environmental costs of re-building the utility of these materials will be higher.

It should be noted that in the case of energy using products, applying circular economy principles that aim at prolonging the lifetime of a product without improving its efficiency is not always beneficial in terms of CO_2-eq emissions reductions. Indeed, in some cases, the additional CO_2-eq emissions associated to the production of the replacement product are more than compensated by the reduction of CO_2-eq emissions linked to the higher efficiency in use of this replacement product. This is illustrated by some of the findings presented in this study, but it should be kept in mind that the focus of these calculations is purely on CO_2-eq. emission impacts, and other aspects (e.g., water use and material scarcity) were not taken into account.

Policy measures or managerial/individual decisions can increase the volume of material through these loops (*e.g.* Ecolabel requirements listed in Annex B). Some measures impact several of these loops simultaneously, and thus have a broader impact on the material volumes entering and exiting the circular system.

1.2. Report structure and overview

This report presents first order estimates of the CO_2-eq. emissions impact that could be derived from looking at potential circular economy interventions on the European market. This report is structured as follows:

- Chapter 1. Introduction – establishes the context and motivation for this study.
- Chapter 2. Methodology – a summary of the approach taken in preparing the emissions reduction estimates, including the product categories and reference products analysed and the critical circular economy considerations.

- Chapter 3. White-Goods and Related Products – an analysis summary and emissions reduction estimates for appliances such as washing machines and refrigerators.
- Chapter 4. Lighting Products – an analysis summary and results for lighting products, including lamps and luminaires and the natural transition in the market to solid-state lighting.
- Chapter 5 Consumer Electronics and Related Products – an analysis summary and results for consumer electronics such as televisions, computers and other similar equipment.
- Chapter 6 Motors, Motor Systems and Related Products – an analysis summary and results for motor-related equipment covered under the Ecodesign Directive.
- Chapter 7 Heating and Cooling Products – an analysis summary and results of the products used for heating and cooling our buildings.
- Chapter 8. Windows – a discussion of the emissions reduction potential for windows.
- Chapter 9 Conclusions and Next Steps – an overview of the findings and recommended next steps for this field of study.

2. Methodology

2.1. Product categories and reference products considered

At the moment there are more than 30 product groups (also called product "Lots") which are regulated under the ecodesign and energy labelling directives (or for which final drafts of the regulations are available). Within the scope of this study, it was not feasible to assess the potential recyclability improvements and related CO_2-eq. emissions reduction potentials for each individual product group. Therefore, these 30 product groups were divided into five product categories, and a representative product was selected from each product category for analysis. The findings calculated for the representative product were then extrapolated to all the other products within the product category which had not been analysed. The theoretical potentials of other types of improvements were assessed for each individual product group.

The dozens of energy using products covered under the ecodesign and energy labelling directives were divided into five product categories:

- White goods and related products;
- Consumer electronics and related products;
- Lighting products;
- Motors and motor systems; and
- Heating and cooling products.

In addition, windows, which is an energy-related product (i.e., not an energy using product) was the subject of a specific analysis within the scope of this study.

Some products covered by Ecodesign were excluded either due to the specific nature of the products or to our assessment of there being a limited potential for impact from a circular economy approach. The products not included in this analysis were machine tools, industrial ovens, taps and shower heads[6] and heating products that use energy sources other than electricity. The heating products had to be excluded because any impact on total CO_2 emissions for these products from an LCA perspective or circular economy aspect compared to the CO_2 emissions from the use phase was reported to be less than 2% of total emissions[7].

A list of the covered products, five product categories, representative products and rationale for selection is provided in Annex A.

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[6] Machine tools and industrial ovens are customized, have long lifetimes and are not produced in large quantities, and taps and shower heads have long lifetimes compared to the use of material that they represent.
[7] The Ecodesign ErP Preparatory Study estimates that "98 to 99,9% of all CO_2 emissions relate to the use phase", thus the CO_2 emissions from all the other stages of this product's life-cycle would be between 0.1 to 2%. Furthermore, any impact due to consideration of the LCA or circular economy principles would constitute a fraction of the 0.1 to 2% of CO2 emissions, meaning the overall potential would be very limited.

In order to offer a clear and comprehensive overview of the potential CO_2-eq. emissions reductions that could be delivered through applying the principles of the circular economy, this report estimates the potential reductions by product group that could be delivered through a range of different approaches, including:

- Improved recyclability;
- Extended service life;
- Service economy approach (lease, pay-per-unit-of-service, etc.); and
- Improved refurbishment (modelled as one of the scenarios under "service economy approach").

2.2. Limitations

This study is exploratory in nature and is meant to provide first-order estimates of the range of possible circular economy impacts on greenhouse gas emissions. Limitations had to be established concerning the scope and depth of analysis of the study. These limitations include:

- Environmental impacts assessed - only CO_2 emissions impacts were analysed in this study, although other environmental impacts would deserve a similar analysis;
- Analysis boundaries - the whole life cycle of the products analysed was covered in this study, from extraction of materials through to disposal; however impacts beyond the product boundary (e.g., factory retooling and exogenous infrastructure upgrades) were considered outside of scope;
- Technological obsolescence - some aspects of the "smartness" and rapid evolution of products are expected to have impacts on energy in use as well as useful service life. However, this impact was not assessed in this study because forecasting the interplay between technology evolution and consumer demand would be very complex and difficult to predict at this stage, and thus was considered outside of scope.
- Deep design re-think – strong policy and/or price incentives to extend the lifetime of products and/or make them more easy to maintain, refurbish, dismantle or recycle may impact the design of product quite deeply. However, this impact was not assessed in this study because forecasting this type of hypothetical future evolution is impossible at this stage.

The focus of the study is on the potential for additional CO_2 savings, rather than the specific policy measures that would achieve these. The focus of the calculations is on the kg CO_2-eq. impacts, based on data sources of EC studies, including primarily Ecodesign preparatory studies. This may mean that the impact on CO_2 emissions of material considerations may be under-represented.[8] Therefore a

[8] For more information on this assessment of underestimated environmental impact factors, please visit: http://www.eup-network.de/fileadmin/user_upload/BIO_IZM_WI_material_efficiency_MEErP_stakeholder_consultation.pdf?PHPSESSID=7788d4a643fd02aed4c15559269573dc

sensitivity assessment was made of the consequences of 30% higher impacts for all lifecycle stages except use phase. This assessment is presented in Annex N, and concludes that the impacts of using these sources is not likely to have a major influence on the conclusions drawn for white goods although it may slightly impact findings related to non-tertiary coffee machines and professional refrigeration equipment.

2.3. Circular economy approaches considered

2.3.1. Improved recyclability

Improved recyclability refers to the impact of increasing the share of valuable materials recycled for the share of products that is expected to be recycled in 2020. It was assessed on the basis of a literature review focusing on the representative product for each product category. In other words, after estimating the impact of potential requirements for at least one representative product per product group (as listed in Annex A) based on existing literature, we assumed that improved recyclability was linked to reduced environmental impacts in the production and disposal stages of the LCA, by calculating the ratio:

$$\frac{CO2 - eq.\, emission\ impacts\ of\ improved\ recyclability}{CO2 - eq.\, emission\ impacts\ of\ the\ production\ and\ disposal\ phases}$$

We then apply this ratio from the representative product to the other products in the same product group to estimate the broader potential impacts across all covered products. Assumptions had to be made concerning the current and future recycling rates. Please see Annex C for a discussion of this issue.

2.3.2. Extended service life

Extended service life refers in this study to increasing the average in-use lifetime of products. For most products this would be equivalent to improving their durability, however for certain consumer electronics (e.g., televisions or mobile phones), it may be common for the in-use lifetime to be shorter than the functional lifetime. When this happens working products are discarded in favour of those with improved performance/features/function. For these products, extended lifetime can be achieved through a combination of other initiatives and incentives (for example, different commercial models, improved upgradability, etc.).

In their study *Integration of resource efficiency and waste management criteria in European product policies – Second phase – Report n° 1 Analysis of Durability* [JRC, 2012a], the Joint Research Centre (JRC) defined a methodology for quantifying the impacts of lifetime extension, taking into account the relative efficiency of replacement products. This approach can be used to quantify the benefits of either functional or in-use lifetime extension. It was therefore applied to all products and the input data includes CO_2 equivalent emissions attributed to each stage of the product's life cycle and the average product lifetime. All this information is extracted or extrapolated from the ErP Preparatory

Studies, except where this information is available in studies focused on a product LCA. In the absence of estimates concerning the evolution of the CO_2 equivalent emissions attributed to aspects other than energy in use, the data available in the ErP Preparatory Studies was used as it is. Concerning the use stage, the expected efficiency improvements were taken into account as projected in the sources mentioned in 2.4. This correction factor corresponds for each product to the percentage efficiency improvement between 2010 and 2020 estimated from data in the ErP Preparatory Studies.

Greenhouse gas emission reduction potentials are derived from a set of market scenarios which are based on the following:

- the number of additional years of product service life;
- an assumption of the estimated extra % CO_2 emissions linked to additional reparation and maintenance during the extended lifetime, expressed as a percentage of the impacts of production and end-of-life; and
- the efficiency improvement of the replacement product, the arrival of which is delayed by the extended lifetime.

The efficiency improvement of the replacement product is linked to the lifetime considered for the initial product and based on the percentage efficiency improvement between 2020 and 2030 estimated from data from the ErP Preparatory Studies and expert input from the European Commission [DG Energy, personal communication, October 2015].

Assumptions are made for these three parameters on a case-by-case basis. The numbers are presented in the following sections (and in more detail in the Annexes). Results are presented for a one-year extension of the lifetime and for what is identified as the technically optimal extension based on the balance of energy efficiency of replacement products against the sharing of manufacturer and end-of-life impacts over a longer period. This optimal extension is obviously limited by model complexity and available information and assumptions, and the general rule followed in the model was that the upper limit was defined as doubling the initial average lifetime, with a maximum of 10-years.In the case of Smart Phones, recent research shows that the average functional lifetime may already have been increasing spontaneously [Green Alliance, 2016] and the scenario presented here may be considered as conservative.

2.3.3. Service (performance) economy mechanism

The service economy approach refers to the hypothetical impact of the generalisation of a service offering based on a new economic model that charges for the service provided by a product, rather than on ownership of physical product itself. In the literature, circular economy pioneer Walter Stahel uses the term “performance economy”[9] – referring to an approach where suppliers lease products that

[9] See interview in http://www.makingitmagazine.net/?p=6793

provide services rather than selling the products themselves. Another approach would be to encourage product and appliance sharing, whereby more than one household has access to equipment, increasing its usage rate – such as a communal laundry machines or copiers/printers (N.B. whilst the appliance sharing scenario is not specifically modelled in this study, it could present an interesting area for future investigation - the scenarios developed for leasing in this study result in saving estimates that are comparable to what could happen when sharing resources, but a sharing scenario would deserve a dedicated product by product analysis). The approach involves a re-think of the service needs, purchases and thus business opportunities of services rather than products. In this approach, the service provider typically remains the owner of the products which are leased to the end-user / tenant who accesses those services. This approach offers the following potential benefits:

- Lower consumption of critical resource per unit of service;
- Improved product maintainability, reusability and "refurbishability" driven by the procurement demands of the leasing entity; and
- Higher probability of end of life recyclability.

By removing the barrier of high upfront prices typically associated with products offering high quality, extended service life and efficiency, leasing could significantly increase the proportion of high-quality products in use, typically with the highest energy efficiency and longest lifetime[10]. In the case of a broad market adoption of this type of service contracting, as the manufacturers or specialised leasing companies retain the ownership of the machines during their whole life cycle, the companies will have a financial incentive to optimise their design for easy refurbishment, dismantling and recycling, especially if policy measures and other initiatives are introduced that more directly map end-of-life responsibilities to leasers and manufacturers.

This new business model could shift the market towards higher efficiency, especially if leasers are incentivised to procure the best on the market in terms of energy-efficiency, extended service life, etc. – for example, washing machines built with high-quality components and that require the least maintenance/have the longest life expectancy are also likely to be the most efficient machines[11]. Another example might be industrial compressors, where there is a possibility for electrical sub-

[10] As noted by the Ellen Macarthur Foundation on their website - http://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/in-depth-washing-machines - the carbon savings generated by the choice of an efficient product "could be partially offset by missed energy efficiency improvements that would have been more readily available if the household bought a new machine more often. It is therefore important that such gains—which are largely driven by optimising temperature, spin rate, and washing time—are also accessible to users of 'built-to-last' machines. Fortunately, energy efficiency-enhancing features such as wider ranges of programmes, automatic load detection, sensor technologies, and auto dosing systems are usually a matter of software, electronics, and sensor systems— components that could be reintegrated into machines post production without substantially changing their structure. Providing updating and upgrading washing machine programmes after the first sale can be, therefore, a way to offer energy efficiency improvements without regularly replacing the whole machine".

[11] This is due to the fact that the quality of the sensors that are needed for an efficient machine are quite costly and the proposed machines therefore needs to be of good quality on all aspects to convince consumers.

metering, so the service provider could pay some or all of the energy bill and simply sell their customers cubic meters of compressed air. With the advent of smart products and connectivity developing so rapidly, it will become easier for end-users to see how much their equipment consumes (and costs), making energy efficiency a more and more compelling marketing argument.

For the service economy, the impacts of the development of service-based contracts and sharing are assessed following two scenarios: a limited adoption (LA) of service economy schemes and a broad adoption (BA) of service economy schemes. Input data includes CO_2-equivalent emissions attributed to each stage of the product's life cycle and the average product lifetime.

For each scenario, assumptions are made for each product analysed on a case-by-case basis on:

- The adoption rate;
- The average usage period of a product used for a leasing compared to the usage period of the base-case. Two different increased lifetimes are considered, associated with the low or the high adoption rate scenarios. The assumption is that if the service economy becomes a large part of the market, there will be an incentive for manufacturers to build long-lasting equipment that can easily be maintained, refurbished and recycled;
- The impact of additional refurbishment and maintenance, expressed as a percentage of the CO_2 eq impacts of non-use stages and proportional to the additional lifetime (this additional impact is to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of user the impact of cosmetic changes and transport);
- The average efficiency of the product used for a leasing compared to the average 2020 product. For products with a lifetime of 10 years or more, the percentage improvement between 2020 and 2030 estimated from data from the ErP Preparatory Studies and [DG ENER, personal communication, October 2015] is taken as the default value. For products with a lifetime of less than 10 years, the percentage improvement is increased proportionally to the lifetime, using the same yearly improvement as between 2020 and 2030, based on the assumption that service providers would want to offer their customers a "next generation" product that could be leased for its full lifetime without becoming obsolete[12]. To test the sensitivity of these assumptions, a scenario is also given in which the efficiency of the leased product simply follows the average. Unlike extended service life, the hypothesis for the service economy is that the extended lifetime of products would not postpone the penetration of more efficient products, relying on the better refurbishability of these machines. This is equivalent to considering that towards the end of their base-case lifetime, leased products undergo a refurbishment that brings them to the level of efficiency of the current market average – although in reality this could of course be a more gradual process.;

[12] By applying refurbishment principles, the leased machine is likely to be at least as efficient as the market average even after many years in service. However, in the absence of estimates on the upgradability beyond certain levels of efficiency, we only consider the savings in use during a period that would correspond to the lifetime of the base-case.

- The impact of a better design for dismantling and recycling, expressed as a percentage of the CO_2-eq. emission impacts of the extraction of material and of the end-of-life for the base case.

Table 1 summarises the default values and approaches used for each scenario considered for the service economy. Although we tried not to modify too many parameters for transparency purposes and to allow a comparison between product groups and product categories, these scenarios were adapted for some products as deemed appropriate.

Table 1. Summary of default assumptions under each scenario of the "service economy"

Factor	Limited Adoption Scenario (LA)	Broad Adoption Scenario (BA)	Improved refurbishment / Average efficiency Scenario (IR-BA)
Adoption rate	10%	50%	
Impact of refurbishment and maintenance	One repair/refurbishing/upgrading transaction would take place every five (5) years during the life of the leased machine, each equivalent to 10% of the impact of initial production.[13]		
Lifetime	The average lifetime of a leased product is assumed to be 1.5 times longer than the average non-leased product.		
Efficiency	Leased products are assumed to be about one generation (maximum 10 years) ahead of the average non-leased product in terms of efficiency in use.		Same efficiency as average non-leased product.
Impact of a better design for dismantling and recycling	0%	A one-time 20% reduction of the CO_2-eq. impacts of the extraction of material and of the end-of-life for the base case	

Concerning the use pattern, the hypothesis is that it would not be affected.

2.3.4. Improved refurbishment

Improved refurbishment corresponds to one of the scenarios modelled to assess the impacts of a service economy approach. It is understood that the potential impacts of improved refurbishment would vary depending on how and when a product is refurbished. Due to the fact that only a small proportion of end-of-life products currently get refurbished[14], this approach seems unlikely to significantly increase in the absence of policy tools or strong market forces as it would be the case on

[13] The impact of each transaction used to estimate the impact of extended service life is 10% of the initial impact of production and end-of-life. We made this impact quite significant here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport.

[14] See estimate for washing machines: http://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram/in-depth-washing-machines

the “service economy” model. Thus, the ‘improved refurbishment’ scenario is considered in this study as one consequence of the development of a service economy. The potential impacts of improved refurbishing are therefore presented as one of the scenarios under the “service economy”.

2.4. Data sources

Data for the representative products has been derived from a number of sources, including recent Life Cycle Assessment (LCA) studies as well as Ecodesign ErP Preparatory Studies (PS) and Impact Assessment studies. To ensure that the findings take into account the most recent research, where possible LCA studies have been used for as many products as possible (see Table 1 below).

Table 2. Sources of data for the estimates by representative product type

Product group	Representative product analysed	Data sources *
White goods and related products	Dishwashers	PS, [JRC, 2015a], [JRC, 2012b], [Ricardo, 2015]
Consumer electronics and related products	Television and computer displays	PS, Analysis for the review of Ecodesign and Energy Labelling Regulations, [JRC, 2012b], [JRC, 2014], [JRC, 2015b], [Bhakar, 2015], [Oko Institut, 2012] , LCA studies
	Mobile phones	[BIO, 2014], LCA studies: [Ercan, 2013], [Güvendik, 2014], [Zink, 2014]
	Printers, notebooks	PS, [JRC, 2012b], other LCA studies for verification
Lighting Products	Non directional Lamps	LED Lamp LCA Study [US DOE, 2012]; Lighting Regulation Review Study [DG Energy, 2015]
Motors and Motor Systems	Electric Motors	PS, methodology from [JRC, 2012a], [JRC, 2012b], [JRC, 2012c]
Heating and Cooling Products	Room Air Conditioning	PS, methodology from [JRC, 2012a], [JRC, 2012b], [JRC, 2012c]

* Note: “LCA studies” represents data sourced from recent LCA studies and “PS” represents data sourced from the Ecodesign ErP Preparatory Studies and Ecodesign Impact Accounting study.

Several studies have shown that the environmental impacts of lifecycle stages other than the use phase may be underestimated in the ErP Preparatory Studies ([EEB, 2009], [Oko Institut, 2012]). Therefore, an assessment was made of the consequences of 30% higher impacts for all lifecycle stages except use phase. This assessment is presented in Annex M and concludes that the impacts of using these sources is not likely to have a major influence on the conclusions drawn for white goods although it may slightly impact the findings related to non-tertiary coffee machines and professional refrigeration equipment.

Sales data and efficiency projections rely on information from [VHK, 2015] and [European Commission, 2015a] for all products except Mobile phones for which [BIO, 2014] was used. Information and projections from these studies were reviewed and adjusted if obsolete, based on expert knowledge and reports like [Topten, 2015]. The saving estimates for adopted or planned Ecodesign and Energy Labelling Regulations are all based on [ECOS, 2015].

2.5. Relative magnitude of emissions reduction

In order to give some perspective on the results, the findings are compared to the estimated impact of adopted or expected ecodesign regulations. This comparison is not always straight-forward as the potential emissions reduction derived from the application of the circular economy principles are calculated for the full life cycle of products sold in a given year rather than for the full stock of products in a given year. This makes the comparison with the emissions reduction delivered by ecodesign somewhat approximate. However, although it does not reflect exactly when the emissions would be avoided, this comparison offers a relative scale on which to assess the magnitude of the potential.

2.6. Time horizon

In this study we consider the potential impact of applying the principles of a circular economy to the products sold in 2020. This is considered as a realistic time horizon for the framework (standards, legislative pieces) to be in place and the requirements to start entering into force. When assessing the impact of a lifetime extension, the approach followed uses a common time horizon which is the lifetime of the baseline functional unit; we then normalise the rest of the values to this baseline lifetime. For example, if the lifetime of a product is doubled the impacts of its production and end-of life would be divided by two. The energy consumption of this same product over its whole lifetime would be compared to the consumption of two subsequent products, the second of which would have the efficiency of the average sales of its year of its entry into service.

3. Estimating the potential for white goods and related products

The product category of white goods and related products encompasses household appliances such as refrigerators, washing machines, clothes dryers and dishwashers. The representative product type selected from this group for analysis was the dishwasher.

3.1. Detailed analysis on the representative product

The primary data source used for this analysis was "*Environmental Footprint and Material Efficiency Support for Product Policy – Report on benefits and impacts/costs of options for different potential material efficiency requirements for Dishwashers" [JRC, 2015]*. In this study, the JRC follows its method of assessing and improving the resource efficiency of energy-using products, with a particular focus on end-of-life.[15] This study covers the following resource efficiency criteria: reusability / recyclability / recoverability, recycled content, use of hazardous substances and extended service life through an analysis of the Printed Circuit Board (PCB), Liquid Crystal Display (LCD) screen and pumps and the extension of the lifetime of the dishwasher. Other options were deemed not relevant by the JRC experts.

The following circular economy aspects were analysed for dishwashers in Europe based on this source data and the aforementioned methodology followed:

- **Improved recyclability** – an assessment of combined treatment (improved extraction) and estimates the potential amount of metals potentially recovered from a dishwasher [JRC, 2015], assuming about 50% of the dishwashers in the European waste stream could benefit from this requirement (i.e., approximately 4.1 million dishwashers annually).

- **Extended service life** – In this study, we modelled the effect of an extension of the lifetime from 1 to 10 years based on the JRC methodology and data sources listed in section 2.4. An important difference with the JRC study is that the efficiency of the products on the market in our scenario is projected to increase by over 17% over the lifetime of the initial base case product (based on [European Commission, 2015a]), whereas the efficiency improvement assumed by the JRC is much lower.

- **Service economy** – an assessment of three different scenarios:
    - **Limited Adoption** (LA) assumes 10% of the market adopts an appliance leasing arrangement where the average life of the leased dishwasher would be 1.5 times longer[16] and would have energy consumption over 17% lower than a typical (base-case) machine[17]. It assumes that one repair/refurbishing/upgrading transaction would

[15] For more information on the JRC's approach, visit: https://ec.europa.eu/jrc/en/news/new-method-assess-resource-efficiency-products
[16] Corresponds to the life expectancy of a high-end machine compared to the usage period of the base-case.
[17] Based on data from DG Energy, personal communication, October 2015.

take place every five (5) years during the life of the leased machine, each equivalent to 10% of the impact of initial production[18].

- **Broad Adoption** (BA) assumes 50% of the market adopts an appliance leasing arrangement. Average lifetime, efficiency and impact of repair/refurbishing/upgrading are kept the same as for the LA scenario. This scenario also assumes an impact of better dismantling and recycling that would lower by 20% the impact of material extraction and end-of-life.
- **Improved refurbishment[19]** / Average efficiency (IR-BA) uses the same assumptions as BA but adopts the average energy efficiency of the 2020 sales. In other words, this scenario assumes that the service economy schemes have no impact on the efficiency of the selected products.

These improvement options were built and assessed in comparison with a Business as Usual (BAU) scenario – an assessment of the CO_2 equivalent emissions in 2020 for the base case, assuming no further policy measures or actions on dishwashers.[20]

The table below presents the results of the baseline scenario and the circular economy aspects analysed for dishwashers.

[18] The impact of each reparation used to estimate the impact of extended service life is 10% of the initial impact of production and end-of-life. We made this impact quite significant here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport.
[19] As explained in the methodology section, the environmental impacts of an improved refurbishment are considered as one aspect of what would happen by applying circular economy principles. The scenario in which circular economy is considered not to have any impact on the average initial efficiency of the appliances actually corresponds to an improved refurbishment.
[20] The JRC study presents slightly different findings compared to the earlier ErP preparatory study for dishwashers, however the JRC report is focused on this topic and offers a more up-to-date analysis.

Table 3. Life Cycle Assessment Impacts of the Dishwasher representative unit and Circular Economy impacts for 2020 sales of Dishwashers

Life cycle impacts per unit						
		Materials	Production	Use	Disposal	Total / unit
	units	(kg CO_2-eq.)	(kg CO_2-eq.)	(kg CO_2-eq.)	(kg CO_2-eq.)	(kg CO_2-eq.)
Business as Usual		140	13	1,700	6	1,859
Circular Economy Aspects for the 2020 Dishwasher sales						
Results for 2020 Dishwashers (2020 stock for ecodesign)		A. Benefits of CE measure	B. Life Cycle impacts of the product group	(A divided by B)	C. Benefits of ecodesign and labelling measures	(A divided by C)
	units	(kt CO_2-eq.)	(kt CO_2-eq.)	(%)	(kt CO_2-eq.)	(%)
Improved Recyclability		3	17,167	0.02%	1,600	0.21%
Extended Service Life	1 year life extension	28		0.16%		2%
Extended Service Life	Optimal life extension	120		0.70%		8%
Service Economy	Estimated benefit - LA - 2020 sales	227		1.32%		14%
Service Economy	Estimated benefit - BA - 2020 sales	1,225		7.14%		77%
Service Economy	Average efficiency - IR-BA - 2020 sales	123		0.72%		8%

Note: [JRC, 2015a] assessed the impact of extended service life assuming that 20% of the dishwashers would extend their lifetime by 4 years, delaying the purchase of a replacement unit with the same energy efficiency; and 80% of the dishwashers would see their lifetime extended by 3 years, delaying the purchase of a new dishwasher between 5% and 10% (average 7.5%) more energy efficient [JRC, 2015]. Under this scenario, JRC estimates that the CO_2-eq. impact of extending the lifetime of a dishwasher would save approximately 15 kg CO_2-eq. per unit, which equates to approximately 120 kt CO_2-eq. for the European market of 8.3 million dishwashers per year [JRC, 2015]. This corresponds to about 10% of the expected emissions reduction from ecodesign and labelling measures. The difference with our results illustrates the importance of the product efficiency projection.

The following offers some discussion on the individual circular economy measures presented in the table above for dishwashers:

- **Improved recyclability** – From this analysis, the life cycle benefit related to the improved extraction of key components in terms of CO_2-eq. emissions is estimated to 3 kt CO_2-eq. for the whole dishwasher product group. The results shown in the above table show that although non negligible in absolute terms, the impact of a better recyclability is significantly lower than the impact of ecodesign and labelling measures on the CO_2-eq. emissions associated with dishwashers.

- **Extended service life** –When emissions reduction estimates are projected forward based on the Ecodesign Impact Accounting study[21], experts forecast that over the lifetime of products sold in 2020 the efficiency of dishwashers would increase by about 17%. Under these conditions our model finds slightly higher total CO_2-eq. emissions from prolonging the lifetime of dishwashers. This analysis should of course be revised as efficiency of dishwashers increases and expected future efficiency improvements decrease.

- **Service economy** – It appears from these results that the impact of the uptake of leasing schemes on CO_2-eq. emissions from dishwashers could be of the same order of magnitude as the ecodesign and labelling regulations. The magnitude of this impact, besides the level of adoption itself, would greatly depend on the associated higher efficiency of the products leased. Indeed, the estimated benefits of the scenario in which the development of a service economy has no impact on the efficiency of the products, corresponding to an **improved refurbishment** scenario, are very limited compared to the broad adoption scenario.

Main findings of Dishwasher Circular Economy analysis

The analysis of the circular economy options for dishwashers shows that simply improving recyclability is not enough to generate significant additional CO_2-eq. emissions reduction, although there may be benefits for other environmental impacts not evaluated in this study. Extended service life also has relatively low impact, although the net benefit of increasing lifetime would strongly depend on the efficiency improvement of the replacement dishwashers. The service economy option seems to offer the most promising improvement potential for additional CO_2-eq. emissions reduction, with the potential impact of leasing strongly dependent on the assumption that higher efficiency models be offered through such schemes. Thus, the shift to a business model that accelerates the development of the service economy approach is an opportunity for policy makers, to influence that market shift, and trigger even more beneficial impacts (the policy framework could reward the manufacturers that make their appliances both energy efficient and long lasting).

3.2. Extrapolating the representative product to the group of products

Having prepared an estimate of the circular economy market impacts for dishwashers, the next step in our analysis is to extrapolate those impacts to the larger group of products – white goods and related products. This extrapolation was prepared and presented for each of the circular economy options considered. Please see Annex E for detail on the data, hypothesis and results for each individual product type within the white goods and related products group.

[21]The Ecodesign Impact Accounting study is available on line at the following link: https://ec.europa.eu/energy/sites/ener/files/documents/Ecodesign%20Impacts%20Accounting%20%20-%20final%2020151217.pdf

Improved recyclability

Improving the recyclability of a product helps to reduce the environmental impacts of the production and disposal stages. For dishwashers, the ratio between the impact of these stages and the benefits of the improved recyclability is about one half of one percent (0.5%)[22]. We therefore apply this ratio to the total CO_2-eq. emissions attributed to the production and end-of-life for all the products in the white goods and related products group, as they were presented in the ErP preparatory studies. These impact estimates are then scaled up to the 2020 sales estimates from the ErP preparatory studies, with the assumption that the improvements will impact 50% of large white good appliances [JRC, 2015], 40%[23] of the smaller white goods and 75% of the large white goods used in the tertiary sector.

Extended Service Life

Extending the service life of a product yields more useful service for a given product or appliance. We observed large differences in the net impacts of extended service life on the CO_2-eq. emissions linked to the life cycle of the products. These variations are explained by differences in the rate of energy-efficiency improvements and the relative share of the use stage vs. other stages concerning the CO_2-eq. emissions. For several products, even a limited increase of the lifetime was found to have a negative impact on CO_2-eq. emissions. Further, the benefits of prolonging the lifetime could be reconsidered in a few years, with updated information on the pace of energy efficiency improvement and the relative share of the use stage vs. other stages on the CO_2-eq. emissions.

Two important factors warrant a specific mention. The lifetimes used for this analysis were taken from the ecodesign preparatory studies, which tended to be longer than other references, and thus had an impact on the calculated benefits of extending the lifetime. For professional refrigeration equipment, the CO_2 benefits of an extended lifetime would have been high in the former or even current situation due to the high impact of the "disposal" stage. However, with the refrigerant gases being more and more effectively recovered and the fact that refrigerant gases with a significantly lower global warming potential (GWP) are becoming the norm (due to the effect of the F-gas Regulation), the benefits of extending the lifetime diminish over time.

Service Economy / Improved Refurbishment

Service economy options were modelled for dishwashers, tumble driers, washing machines, domestic refrigerators and freezers, vacuum cleaner, kitchen appliances, domestic coffee machines, professional wet appliances and driers, professional refrigeration equipment and commercial refrigeration equipment. For professional and commercial refrigeration equipment, although all scenarios are modelled as for other products to allow comparison, the potential impact of a broad

[22] According to our analysis of [JRC, 2012] this ratio seems to be slightly higher for washing Machines but remains under 1%, thus confirming the order of magnitude of the impacts.
[23] Assumes a smaller share will access the specialised end-of-life treatment than does so for larger products.

adoption should in our view be considered cautiously as leasing of this equipment already constitutes a significant part of the market and the complexity of the functions served by these products and potential split-incentives may lead to adverse outcomes[24]. For coffee machines and vacuum cleaners, similarly, all scenarios are modelled as for other products but the potential impact of a broad adoption may be more difficult to achieve than for other products. This is due to the fact that these appliances have a lower purchase price relative to other white-good appliances and consumers may not choose to lease these products.

[24] Display cabinets in particular serve the function of maintaining the food at the desired temperature but also displaying it to consumers. Their characteristics can therefore impact sales. As a consequence, if the service offered in the case of a “service economy” approach focuses on sales more than on energy per m^3 of refrigerated product, such an approach may have a negative impact on CO_2-eq. emissions.

Table 4. Overview of impacts from improved recyclability, extended service life and service economy for white goods and related products

White Goods	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended Service Life, 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Avg. efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years (baseline years)				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Dishwasher	3	-208	0	0 (15)	227	1,225	123	1,600
Tumble drier	2	-145	0	0 (13)	165	858	71	2,000
Washing machine	15	-267	0	0 (15)	257	1,525	327	2,300
Domestic refrigerators and freezers	12	-742	0	0 (16)	750	3,921	144	4,100
Vacuum cleaners	11	301	1,762	6 (6)	308	1,766	1,014	8,000
Kitchen appliances	8	-421	0	0 (16)	425	2,277	116	2,000
Non-tertiary coffee machines	2	-60	0	0 (6)	94	502	147	1,000
Professional wet appliances and dryers	2	-320	0	0 (9)	296	1,504	65	4,000
Professional refrigerating equipment	10	-90	0	0 (10)	340	1,948	634	7,000
Commercial refrigerators and freezers	6	-165	0	0 (8)	275	1,487	382	7,600

3.3. Findings of the circular economy impacts for white goods and related products

For the options considered for white goods and related products, the **service economy** approach offers the greatest potential CO_2-eq. savings.

The impact of an improved **recyclability** on the total CO_2-eq. emissions associated with this product category represents, for each product group, less than 1% of the impact of ecodesign and energy labelling measures, therefore this option is unlikely to currently be relevant from the standpoint of CO_2-eq. emission reductions to develop an intervention mechanism. This low impact can be explained by the fact that the expected effect of the RoHS and WEEE Directives are already included in the BAU scenario and by the fact that recycling represents a higher loss of value (i.e., use of energy, waste of part of the material) than other ways to improve material efficiency. It should also be noted that these figures reflect the current situation, but the impact of material extraction is likely to become a greater concern as resources become increasingly scarce, in which case the benefits of improved recycling will become higher (see discussion in Annex C).

The impact of **extended service life** varies significantly between products, depending on the share of the use stage in the total CO_2-eq. emissions and the expected efficiency improvement of the replacement products. For most of the products considered in white goods and related products, the extending service life appears to result in an increase of the total CO_2-eq. emissions. However, there are positive impacts for vacuum cleaners[25]. In the case of refrigeration products, the expected impact of the F-gas Directive has been taken into account. With high GWP refrigerant gases and sub-optimal recovery processes, product disposal historically had a significant impact in terms of CO_2-eq., meaning that extending the lifetime of the products represented important emissions reduction. However with new refrigerant gases offering low GWP, extending the service lifetime of refrigeration equipment becomes less advantageous from a CO_2-eq. emissions reduction point of view.

The modelled impacts of the generalisation of the **service economy** approach (broad adoption) to this product category is approximately 17 Mt CO_2-eq. This corresponds to around 40-50% of the impact of ecodesign and labelling regulations for these products. The highest impacts are achieved by coupling this service economy approach to a higher efficiency of the leased product than the average product sold that year. Anecdotal evidence seems to indicate that this is usually the case – leasers chose good quality, long-lasting products which happen to also be the most efficient ones – although additional incentives may be necessary to ensure such behaviour if a leasing approach were to be promoted within the circular economy strategy.

[25] An extension of the lifetime by 6 years represents about 22% of the estimated impact of the existing ecodesign and labelling regulations.

4. Estimating the potential for lighting products

The analysis in this section encompasses all lighting products and equipment, including lamps, luminaires, ballasts and drivers. Lighting is a very important product category which has high environmental impacts caused by the energy consumption in the use phase. The representative product selected for this product category is a mains-voltage, self-ballasted non-directional light-emitting diode (LED) lamp. This was selected because it combines the LED light source, drivers, heat sinks, materials, optics, phosphors and other aspects which can be found in lamps and luminaires across the lighting market.

4.1. Detailed analysis on the representative product

In Europe, lighting technologies based on LEDs are entering the market and displacing conventional light sources like halogen, fluorescent and high-intensity discharge light sources in use across the domestic and professional lighting markets. Ultimately, LED light sources are expected to dominate all general illumination lighting applications in the future - therefore, the scenarios presented in this analysis will look at the CO_2-eq. emission impacts of the circular economy aspects applied to LED lighting.

In estimating the potential for lighting products, this analysis relied on two sources. To quantify the impact of the changes on the representative product - an LED lamp – we relied on an LCA study published by the US Department of Energy, "Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products Part 2: LED Manufacturing and Performance" [US DOE, 2012]. This study offers a detailed assessment of the manufacturing process for high-brightness[26] LEDs used in general illumination and therefore offers a good comparison to LED sources used in these applications. To quantify the magnitude of the changes in the European (EU-28) lighting market, we relied on a recent publication by the European Commission, "Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements, ('Lot 8/9/19'), Final report, Task 7" [DG Energy, 2015]. This study, published in October 2015, offers the most up-to-date estimates of the European lighting market, including all light sources, technologies and end-use sectors.

For our scenario analysis, we use the common non-directional lamp as our representative product for all light sources, and conduct a comparison of market impacts relating to changes to the performance of the LED lamp presented in the US DOE study. The US DOE study provides estimates of the life-cycle impacts of each, normalised to a lighting service of 20,000,000 lumen-hours of lighting service, facilitating comparisons across the lighting market. Building on this foundation of research, following circular economy aspects were analysed for lighting products:

[26] As discussed in the US DOE report, ecoinvent v.2.2 allowed a user to select an LED product, but it was not one used for general illumination. Rather, the LED in ecoinvent v.2.2 was one found in low-power, indicator applications, thus the US DOE report developed its only analysis to estimate the impact of general illumination (high-brightness) LEDs.

- **Improved recyclability** –the US DOE report assumes a 20% recycle rate of used LED lamps. And industry experts from global companies have indicated that used LED lamps are of limited value, thus it is not expected that higher rates of recycling will occur naturally in the market. In order to assess the impact of a policy measure that increases recycling rates above the baseline used in the US DOE study, we consider a scenario where the recycling rate doubles over the US DOE assumed baseline of 20%, reaching a 40% market recycling rate LED light sources.

- **Extended service life** – the representative LED lamp selected for the US DOE report had a 25,000 hour lifetime (note: since validated and exceeded by US DOE L-Prize testing[27]). There are LED lamps offered on the market that range from 10,000 hour up through (claims of) 100,000 hour, however for this analysis, we consider a scenario were the lifetime is extended by one year (assuming 8 hours of use per day) and we also consider a scenario where the lifetime doubles compared to the US DOE study, evaluating the impacts if the lamp lifetime is extended to 50,000 hours. This level was selected as there are professional-grade products on the market today which are rated for 50,000 hours of service.

- **Service economy** – lighting is a sector where companies like Philips Lighting[28] have already started to announce new business models linked to the service economy. The 'service' provided to customers is quality light, and the equipment, installation and maintenance is handled by the service provider (e.g., Philips). This approach will accelerate the market transition to LED lighting as it looks not only to capture new installations, but more importantly it seeks to retrofit existing buildings with highly-efficient, high-quality LED lighting and controls. To quantify the benefit of this approach, we considered three approaches for this product category, and interpolate between the impacts published in the review study report [DG Energy, 2015]:

    - **Limited Adoption** (LA) assumes an acceleration of the existing market penetration of LED lighting provided as a service, such that an additional 20% of the market switches to LED lighting;
    - **Broad Adoption** (BA) assumes an acceleration of LED lighting provided as a service, such that an additional 40% of the lighting market switches to LED lighting.
    - **Improved refurbishment** / Average efficiency (IR-BA) does not apply to lighting, as the LED technology replacing conventional technology is already more efficient, and LEDs themselves are improving in efficiency each year, which is expected to continue through 2030. Thus, this scenario does not apply.

[27] For information on the US DOE testing, see: http://www.lightingprize.org/news_testing_hours.stm
[28] News items about pay-per-lux from Philips: Article 1 Article 2

These improvement options were built and assessed in comparison to a Business as Usual scenario (BAU) – which represents the European lighting market as it stands today, i.e., assuming no new policies are adopted. However, as discussed above, the BAU scenario does take into consideration the natural improvement in LED technology in the baseline, thus the technology shift is incorporated into this scenario and all option scenarios analysed for lighting products.

The table below presents the results of the above circular economy (CE) aspects analysed for lighting:

Table 5. Circular Economy Impacts of the Lighting and Lighting Products Market in Europe in 2020

Circular Economy Aspects impacts for lighting and lighting products, 2020 sales						
Results for Lighting Product sales (2020 stock for ecodesign)		A. Benefits of CE measure	B. Life Cycle impacts of the product category	(A divided by B)	C. Benefits of ecodesign and labelling measures*	(A divided by C)
	units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(%)*	*(kt CO_2-eq.)*	*(%)*
Improved Recyclability		-0.41		0.00%		0.00%
Extended Service Life	1 year life extension	265		0.70%		0.70%
	100% life extension	1,238		3.25%		3.25%
Service Economy	Estimated benefit - LA - 2020 sales	6,399	38,118	*16.79%*	38,822	16.48%
	Estimated benefit - BA - 2020 sales	12,365		*32.44%*		31.85%
	Average efficiency - IR-BA - 2020 sales	*(n/a)*		*(n/a)*		*(n/a)*

* Note: the benefits of ecodesign and energy labelling represent the sum of the benefits in 2020 from EC No 244/2009, EC No 245/2009 and EU No 1194/2012.
** Note: the technology shift is taking place regardless of policy intervention therefore it is included in the BAU scenario and all scenarios analysed for lighting products. For this reason, there are no separate savings estimates associated with this option.

The following offers some discussion on the individual circular economy measures presented in the table above for lighting systems:

- **Improved recyclability** – our analysis found that the CO_2-eq. emissions increase slightly when the proportion of LED lamps recycled increases. The reason for the higher CO_2-eq. emissions is due to the energy involved in recovering and recycling the materials from the LED lamps. Thus, improving recyclability of LED lamps is not an attractive policy option from the standpoint of CO_2-eq. emission reduction, but it is likely to have a very positive effect on other environmental impact indicators that were not assessed in this study.

- **Extended service life** – extending the lifetime of an LED lamp by one year (at 8 hours/day) reduces the CO_2-eq. emissions by nearly 1% relative to the baseline and to the CO_2-eq. emissions reduction of the ecodesign measures for lighting. If the lifetime is doubled, an increase that is still in line with commercially available products available on the market today, the emissions are reduced by slightly more than 3%. This emissions savings are derived from the fact that the same invested material and energy is able to provide a service (luminous flux) for a longer period of time relative to the baseline product. This potential impact is limited because the use phase so strongly dominates the life cycle for CO_2-eq. emissions (even for energy-efficient LED lamps).

- **Service economy** – in these scenarios, the potential positive impacts of delivering light as a service to the EU-28 lighting market appear to be quite attractive. This emissions reduction would add a further 17 to 32% of CO_2-eq. emissions reduction over the baseline. Some companies are already looking into this business model, and it may be beneficial to evaluate policy options that support service economy market mechanisms for lighting products.

Main findings of Lighting Equipment Circular Economy analysis

The analysis shows that circular economy-type intervention that offers the most impact for lighting products would be to work to accelerate the retrofit of existing light sources with LED. The policy measure could, therefore, promote the introduction of service economy business models through entities such as building maintenance companies, energy service companies, lighting companies and other stakeholders who would work accelerate the adoption of LED lighting and create a significant reduction in CO_2 emissions.

4.2. Extrapolating the representative product to the group of products

The results presented in the lighting sector are already scaled up to represent all the lighting products and related equipment across Europe. This is due to the fact that methodology followed in this assessment was to evaluate the lighting technology that is entering all of the end-use applications and sectors. Thus, the analysis presented in the previous subsection takes into account the total EU-28 lighting market, and these results are presented in the table on the following page.

Table 6. Overview of impacts from improved recyclability, extended service life and service economy for lighting products

Lighting Products	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended Service Life - 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	100% life extension	Longer time period				
Units	*(kt CO_2-eq)*	*(kt CO_2-eq)*	*(kt CO_2-eq)*	*(%)*	*(kt CO_2-eq)*	*(kt CO_2-eq)*	*(kt CO_2-eq)*	*(kt CO_2-eq)*
All Lighting Products	-0.41	265	1,238	100% more	6,399	12,365	n/a	38,822

4.3. Findings of the circular economy impacts for lighting products

For the options considered for lighting products, the **service economy approach** seems to offer the greatest potential savings, with between a 17% to 32% savings compared to the CO_2-eq. emissions reduction potential of all the current lighting product regulations.

The impact of improving the **recyclability** of LED lighting products is estimated to have a net increase on CO_2-eq. emissions relative to the baseline. The reason for this increase is due to the energy involved in recovering and recycling the materials embodied in the LED lamps. While it should be noted that other environmental impacts which are not quantified in this study are reduced (and thus on a life-cycle assessment basis, the environment would be better off), the net impact focusing solely on CO_2-eq. emissions associated with higher recycling rates is a net increase and therefore is not an attractive policy option from that perspective. However recyclability could become an attractive option for CO_2-eq. emissions reduction point of view in the future, once the difference in efficiency between existing and new products starts to narrow.

The impact of **extended service life** will yield a slight reduction in CO_2-eq. emissions, on the order of approximately 1 to 3% over the baseline. This reduction is the result of some additional lighting service yield from the same LED product, resulting in an improved ratio of lighting service per unit CO_2-eq. emission. However, since the energy consumed in the use phase dominates the total CO_2-eq. emissions over the service life of a lamp, this effect of increasing light output relative to material consumption has a very small impact. Furthermore, a slight increase in the expected pace of efficiency improvement would likely cancel this potential emissions reduction and even mean that extending the service life of light sources could result in slightly higher CO_2-eq. emissions. For these reasons, it would appear therefore that this option does not warrant intervention.

The impact of the **service economy** approach to these products offers between a 17% (LA scenario) and 32% (BA scenario) reduction in CO_2-eq. emissions relative to the reduction potential of the ecodesign implementing measures for all lighting products. This option therefore does appear to offer a good opportunity for CO_2-eq. emissions reduction relative to the ecodesign regulations for lighting products.

5. Estimating the potential for consumer electronics and related products

The product category Consumer Electronics and related products encompasses consumer electronics such as televisions, computers (including desktops and notebooks) and other similar equipment. The products of this category are the subject of quite numerous LCA studies, more so than for other product groups. This can be explained by the fact that the materials used to produce them are of high value and high environmental impact, and that the current lifetime in-use of many of these products is quite limited.

5.1. Detailed analysis on the representative product

The relative wealth of information and the fact that we observed a significant difference between the results relative to two product groups (displays and printer) suggested it would be appropriate to analyse two representative products instead of one. For the assessment of improved recyclability, both electronic displays and imaging equipment were used as representative products for this product category. Liquid Cristal Displays (LCD) are the representative product type for televisions and computer monitors. Ink jet multifunctional device printers (IJ MFD printers) were used as the representative product type for imaging equipment. For other products an average of the values for these two representative product types was used.

The following circular economy aspects were analysed for LCD displays and IJ MFD printers in Europe based on this source data and the aforementioned methodology followed:

- **Business as Usual (BAU)** – an assessment of the CO_2-eq. emissions in 2020 for the base case, assuming no further policy measures or actions on LCD displays and IJ MFD printers.
- **Improved recyclability** – [JRC, 2012b] reports a recyclability benefit of 24 kg CO_2-eq. for LCD TV of 20.1". We estimate this figure to correspond to about 23% of the impact of non-use phases and apply this ratio to all displays. The same JRC report presents estimates for the recyclability benefits of ink jet printers. We estimate this figure to correspond to about 11% of the impact of non-use phases and apply this ratio to all imaging equipment. Other products in the Consumer Electronics category are assumed to be affected by a recyclability benefit rate of 17% of the impact of non-use phases – between these two values.
- **Extended service life** – an assessment of the impact of extending the lifetime of televisions was made using the methodology from [JRC, 2012a]. The impact of increasing the lifetime by 1 to 10 years was estimated and the lifetime extension that represented the largest reduction was selected, within the limit of doubling the average lifetime of the products.
- **Service economy** – the impacts of the development of service-based contracts are assessed following the same principles as for White Goods - an assessment of three different scenarios:
    - Limited Adoption (LA) assumes 10% of the market adopts an appliance leasing arrangement where the average life of the leased product would be 1.5 times longer.

In the case of televisions, the leased product is assumed to consume as much energy as an average (base-case) TV[29]. A leased imaging equipment is assumed to consume 2% less than a base-case product. This scenario assumes that one repair/refurbishing/upgrading episode would take place every five (5) years during the life of the leased machine, each equivalent to 2% of the impact of initial production for televisions and 10% of the impact of initial production for other products[30].

- Broad Adoption (BA) assumes 50% of the market adopts an appliance leasing arrangement. Average lifetime, efficiency and impact of repair/refurbishing/upgrading are kept the same as for the LA scenario. This scenario also assumes an impact of better dismantling and recycling that would lower by 20% the impact of material extraction and end-of-life.
- **Improved refurbishment[31]** / Average efficiency (IR-BA) uses the same assumptions as BA but using the average energy consumption of 2020 sales, assuming that service economy schemes have no impact on the efficiency of the proposed/selected products.

[29] This high consumption reflects the likely size increase of the screen. This is the expected trend on the market according to [European Commission, 2015b], and would also likely be the case for leasing since this type of offer removes the barrier of a high upfront price.

[30] The impact of each reparation used to estimate the impact of extended service life is 10% of the initial impact of production and end-of-life. We made this impact quite significant here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport. The impact of reparations for televisions was modeled as lower than for other products because product experts found it less likely to happen.

[31] As explained in the methodology section, the environmental impacts of an improved refurbishment are considered as one aspect of what would happen by applying circular economy principles. The scenario in which circular economy is considered not to have any impact on the average initial efficiency of the appliances actually corresponds to an improved refurbishment in the case of TVs.

Table 7. Life Cycle Assessment Impacts of the Televisions representative unit and Circular Economy Impacts for 2020 sales of Televisions

Life cycle impacts per unit						
		Materials	Production	Use	End-of-Life	Total / unit
units		*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Business as Usual		241	106	187	3	537
Circular Economy Aspects impacts for the televisions product group						
Results for 2020 Televisions (2020 stock for ecodesign)		A. Benefits of CE measure	B. Life Cycle impacts of the product group	(A divided by B)	C. Benefits of ecodesign and labelling measures*	(A divided by C)
units		*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(%)*	*(kg CO_2-eq.)*	*(%)*
Improved Recyclability		**6,316**	39,066	16%	33,000	19%
Extended Service Life	1 year life extension	2,307		6%		7%
	Optimal life extension	23,518		60%		71%
Service Economy	Estimated benefit - LA - 2020 sales	812		2%		2%
	Estimated benefit - BA - 2020 sales	5,241		13%		16%
	No efficiency impact - IR-BA - 2020 sales	5,740		15%		17%

The following offers some discussion on the individual circular economy measures presented in the table above for televisions:

- **Improved recyclability** – From this analysis, the potential positive impacts of improving the recyclability of televisions appears to be quite attractive. The emissions reduction would account for as much as 16% of the total life cycle impact of these products in terms of CO_2-eq. emissions. It may be beneficial to evaluate policy options that seek to generalise good practices in terms of design and of end-of-life (i.e. reduction of time for separation of parts / materials for end of life extraction in order to improve economic incentive for recycling).
- **Extended service life** – the impact of extending the in-use lifetime of televisions is found to be advantageous – in terms of avoiding CO_2-eq. emissions – as the replacement products are expected to consume as much energy as the replaced products. The longest lifetime modelled was therefore retained as the optimal scenario and would deliver CO_2-eq. emissions reduction of the same order of magnitude as the Ecodesign and Energy Labelling Regulations.

- **Service economy** – the potential savings associated to the development of a service economy, although quite significant in absolute terms, are for televisions much less dominant than for other products analysed in this study. This is because the expected trend is that leased products would initially consume more than the average baseline television due to a larger screen size and potential additional features. For this reason also, the impact of the scenario with average efficiency, corresponding to an improve refurbishability, is higher than for the other scenarios.

Main findings of the Circular Economy analysis

The analysis of various improvement options for the reference products for consumer electronics and related products shows that in this case where the extraction of material represents a very significant part of the CO_2-eq. emission over the life cycle of the products, improving the recyclability can already make a real difference in additional CO_2-eq. emissions reduction. Extending the service life of products and the “service economy” approach both seem to be promising improvement options for additional CO_2-eq. emissions reduction and in particular the extension of the in-use lifetime which presents the highest potential.

5.2. Extrapolating the representative product to the category of products

Having prepared an estimate of the circular economy market impacts for televisions, the next step in our analysis is to extrapolate those to the larger category of products. This extrapolation was prepared and presented for each of the circular economy options considered. Please see Annex G for detail on the data, hypothesis and results for each individual product type within the consumer electronics product category.

Improved recyclability

The impact of improved recyclability is linked to the environmental impacts of the production and disposal phases. As explained in 5.1,based on literature found for LCD screens and IJ MFD printers, those product groups are assigned recyclability benefit rates of respectively 23% and 11% of the impact of non-use phases and other product groups are assigned an intermediary value of 17%.

These estimated impacts per unit are then scaled up to the 2020 sales as estimated based on data from the preparatory studies and from the Ecodesign Impact Accounting study [European Commission, 2015a], with the assumption that the proposed improvements will effectively impact 85% of the products sold in 2020, is based on expert assumptions. For more information, an overview of data, hypothesis and results per product group is presented in Annex G.

Extended Service Life

The net impacts of extended lifetime on the CO_2-eq. emissions linked to the life cycle of consumer electronics and related products are in general positive and very significant. This is due to the combination of an already high level of energy-efficiency in 2020 and important impacts of other phases of the life cycle, in particular, extraction of materials.

Only computer servers, under the assumptions made for this analysis, don't appear to exhibit life cycle CO_2-eq. emissions benefits from an extended lifetime. This is due to the fact that there is an increasing focus on improving the energy efficiency of data centres, which continues to drive down server energy consumption. As a consequence, the percentage of efficiency improvement expected between 2020 and 2030 is much higher than for other products. In addition, due to their function, energy in use represents a very large share of the total CO_2-eq. emissions generated by servers over their whole life cycle. The benefits of prolonging the lifetime of servers could be re-considered in a few years, with updated information concerning the pace of energy efficiency improvements. For more information, an overview of data, hypothesis and results per product group is presented in Annex G.

Service economy

Service economy options were modelled for televisions and computer monitors, complex set-top boxes, video equipment, game consoles, computer servers, personal computers, smart phones and imaging equipment. Simple set-top-boxes were also considered in the analysis but the market in 2020 is expected to be nearly non-existent, so this product group was disregarded. The percentage of adoption for the "Broad Adoption" scenario is defined as 30% instead of the default 50% scenario to take into account the fact that a significant share of the market is already under a leasing model, through a service offering called "managed print service". For personal computers, the upgrading potential is likely to be very significant. However, some users may not feel comfortable with this option on their computers, and in the absence of robust estimates of the potential (and in the interest of comparability with other products), the hypothesis for personal computers was kept as the default. An overview of data, hypothesis and results per product lot is presented in Annex G.

Table 8. Overview of impacts associated to improved recyclability, extended service life and service economy for consumer electronics and related products

Consumer Electronics	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended Service Life, 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years (baseline years)				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Televisions	6,316	2,307	23,518	7 (7)	812	5,241	5,740	33,000
Computer Monitors	623	167	1,808	7 (7)	121	719	565	0
Simple set-top boxes	0	0	0	5 (5)	0	0	0	3,000
Complex set-top boxes	330	315	1,180	4 (4)	117	686	511	
Video	136	142	897	5 (5)	28	179	190	0
Game consoles	149	175	1,495	6 (6)	1	55	209	0
Computer Servers	279	-714	0	0 (5)	476	2,490	437	16,000
Personal Computers	3,437	4,343	20,202	4.1 (4)	857	4,864	4,571	7,000
Smart Phone	942	2,281	4,887	2.5 (2)	228	1,204	1,263	0
Imaging Equipment	419	853	4,003	4 (4)	148	588	628	1,000

5.3. Findings of the circular economy impacts for consumer electronics and related products

For the options considered for consumer electronics and related products, **extending the service life** of products seems to offer the greatest potential savings.

According to our model based on existing literature, **improved recyclability** of consumer electronics and related products represents an interesting option to lower the total CO_2 emissions associated to the life cycle of these products. For televisions, personal computers and imaging equipment, improved recyclability modelled in this study represents CO_2-eq. emissions reduction between 20% and 50% of those delivered by ecodesign and energy labelling regulations.

The impact of an **extended service life** is generally very positive for these product groups, due to the importance of production and end-of-life phases in the total CO_2-eq. impact. The difference between televisions and computer displays comes from the fact that the transition from CCFL-LCD to LED-LCD screens is taking more time for computer displays than for televisions. Additionally, the size of computer displays is more limited than for televisions, which affects the expected energy consumption of these products. As a consequence, the expected evolution of the importance of the use phase is different between these two product groups, although the technologies are the same. Even with the efficiency improvement expected for computer displays between 2020 and 2030, there is however still a clear case for extending the lifetime of these products, with an emissions reduction potential of the same magnitude as for the Ecodesign and Energy Labelling regulations for tumble driers.

Concerning the effects of a **service economy** approach to these products, the modelled impacts of the generalisation of this approach on the design of products (due to the fact that manufacturers will either remain the owners or will have to deal with external leasers who will be more powerful than simple consumers) seem particularly interesting for electronic displays, computers, smart phones and imaging equipment. For imaging equipment, some leasing approaches already exist for office products, but expanding on this or extending the in-use lifetime of these products could result in impact reductions significantly higher than the current voluntary agreement. A further in-depth analysis of the current situation and actual improvement potential concerning the extended service life of these products should be made before developing potential policy options.

6. Estimating the potential for motors, motor systems and related products

The product category of electric motors, motor systems and related products encompasses these products used in various appliances and equipment, in all end-use sectors. This category of products includes distribution and power transformers, power cables, residential ventilation, ventilation fans, electric motors, building circulator pumps, electric pumps, pumps for waste water, large pumps and pool pumps, special motors and variable speed drives, and compressors. The representative product type selected from this category for analysis was the electric motor.

6.1. Detailed analysis on the representative product

For electric motors, systems and related products, the analysis centres around evaluating appropriate improvements to the equipment based on the best available information. The following circular economy aspects were analysed for this equipment in Europe, following the methodology as previously described for other representative products in this study:

- **Improved recyclability** –in this study, the benefit of improved recyclability was derived from the estimate found for dishwashers compared to the relative percentages of copper in dishwashers versus motors. Copper was the main material which indicated a recyclability improvement in the various scenarios analysed by the JRC [JRC, 2015b]. The share of copper in dishwashers and motors was derived from the respective bills-of-materials presented in the JRC study and the electric motors preparatory study [ISR, 2008]. Dishwashers contain 1-2% copper and the percent improvement (in terms of CO_2-eq. emissions reduction) from better recycling is 0.50%. Electric motors contain about 8% copper, and the percent improvement from better recycling is therefore estimated at 3%. This is consistent with the fact that material recovery from these products is expected to be already high. This percentage is even likely to be overstated because, motors being a much simpler product than dishwashers, material recovery is already widely implemented in the market. The magnitude of this uncertainty is, however, limited in the context of the full life cycle of electric motors.

- **Extended service life**– For products like electric motors where the use phase represents a very large part of the CO_2-eq. emissions over the whole life cycle, extending the lifetime can often only have a limited impact. In this study, we modelled the effect of an extension of the lifetime from 1 to 10 years base on the JRC methodology and data sources listed in section 2.4.

- **Service economy** – the service economy for motor and motor system can already be found in the energy services companies (ESCOs) market, thus these scenarios build on this trend, adapting three approaches for this product category:
    - Limited Adoption (LA) assumes an average service life of a product used in a leasing contract would the same as the service life in a base-case electric motor. The impact

on use would be 10% lower than the impact of the base-case machine (based on the assumption that an ESCO would optimise the dimensioning management and maintenance of the equipment). The repair/refurbishing/upgrading transactions would take place every five (5) years during the life of the leased motor, each equivalent to 10%[32] of the impact of initial production. This LA scenario assumes an adoption rate of 10%.

- Broad Adoption (BA) assumes 50% of the market adopts a leasing arrangement for electric motor services. Other parameters are the same as for the low adoption scenario.
- **Improved refurbishment** / Average efficiency (IR-BA) uses the same assumptions as BA but using the average energy consumption of 2020 sales, assuming that service economy schemes have no impact on the efficiency of the proposed/selected products.

The table below present the results of the baseline scenario and the circular economy aspects analysed for electric motors.

[32] For reference, the impact of reparation calculated to estimate the impact of extended service life is 5% of the initial impact of production and disposal. We significantly increase it here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport.

Table 9. Life Cycle Assessment Impacts of the Electric Motor representative unit and Circular Economy Impacts for 2020 sales of Motors

Life cycle impacts per unit		Materials	Production	Use	End-of-Life	Total / unit
	units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Business as Usual		315	59	22,603	21	22,998
Circular Economy Aspects impacts for the whole product group						
Results for 2020 Motors (2020 stock for ecodesign)		A. Benefits of CE measure	B. Life Cycle impacts of the product group	(A divided by B)	C. Benefits of ecodesign and labelling measures	(A divided by C)
	units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(%)*	*(kt CO_2-eq.)*	*(%)*
Improved Recyclability		89	249,521	0.04%	57,000	0.16%
Extended Service Life	1 year life extension	-879		-0.35%		-2%
Extended Service Life	Optimal life extension	0		0.00%		0%
Service Economy	Estimated benefit - LA - 2020 sales	2,392		0.96%		4%
Service Economy	Estimated benefit - BA - 2020 sales	11,962		4.79%		21%
Service Economy	Average efficiency - IR-BA - 2020 sales	-300		-0.12%		-1%

The following offers some discussion on the individual circular economy measures presented in the table above for electric motors:

- **Improved recyclability** – Based on the assumption that the share of copper is a good indicator of the potential additional benefits from improved recyclability, a ratio of 3% of the CO_2-eq. emissions associated to non-energy-in-use aspects will be applied for motors and motor systems.

- **Extended service life** – Extending the lifetime of electric motors by five (5) years to reach a lifetime of 17 years is found to yield the lowest CO_2-eq. emissions. The CO_2-eq. emission reduction is however limited and this positive result of extending the lifetime is strongly linked to the efficiency improvement estimates taken from [European Commission, 2015a] and which are very low. Indeed, [European Commission, 2015a] projects a 1% efficiency improvement between 2020 and 2030, depending on the conclusions of the review of the existing motor regulation[33]. The validity of this assumption could vary, for example if a 2% improvement is used, our model indicates that extending the lifetime of electric motors would not be a relevant objective to pursue. There is also a risk that extending lifetime may also have perverse effects on the energy efficiency of this equipment if sufficient maintenance is not undertaken. The potential CO_2-eq. saving estimates presented here for an extended service life of electric motors should therefore be considered cautiously.

- **Service economy** – In these scenarios, the potential positive impacts of leasing would only rely on the improved efficiency in use of the electric motors. That would indeed be the main focus of an ESCO that would put in place that sort of leasing contract with an industrial customer.[34] The impact of a scenario with no efficiency improvement is therefore negative under these assumptions, meaning the CO_2-eq emissions would be increasing, not decreasing.

Main findings of Electric Motor Circular Economy analysis

The analysis of various improvement options for electric motors shows that due to the very large part of the CO_2-eq. emissions being linked to energy in use, only improvements linked to a lower energy consumption in use have a significant impact on the total emissions.

6.2. Extrapolating the representative product to the category of products

Having prepared an estimate of the circular economy market impacts for electric motors, the next step in our analysis is to extrapolate those to the larger category of products. This extrapolation was prepared and presented for each of the circular economy options considered. Please see Annex I for detail on the data, hypothesis and results for each individual product type within this product category.

Improved recyclability

The impact of an improved recyclability is linked to the environmental impacts of the production and disposal phases. For the reference product electric motors, the ratio between the impact of these phases and the benefits of the improved recyclability has been estimated to slightly less than 3%. We therefore apply this ratio to the sum of the CO_2-eq. emissions attributed to the production and end-

[33] Commission Regulation (EC) No 640/2009, OJ L 191, 23.7.2009, p. 26–34. This Regulation should soon be replaced by a new measure that will extend the scope. The draft of this new text proposes a review no later than 1 January 2018 for medium voltage motors and no later than 1 January 2020 for the rest.

[34] In this business model, the energy-services company (ESCO) would enter into a leasing contract with a manufacturer in need of electric motor services. The ESCO would be providing rotational torque services and the manufacturer would be paying a fee for that service. Given that electric motors are primarily a business to business product, and there is a direct incentive for the ESCO to use efficient motors in the service contract, the scenario with no efficiency improvement increases CO_2-eq. emissions.

of-life of the products as presented in the Preparatory Studies for the other products in this group. The estimated impacts per unit are then scaled up to the 2020 sales as projected in the Preparatory Studies, with the assumption that the proposed improvements will affect 75% of motors, fans and circulators; and 100% of transformers. For more detail, including the data, hypothesis and results per product, please see Annex I.

Extended Service Life

Based on available estimates from the Ecodesign preparatory studies and the Ecodesign Impact Accounting study, the expected efficiency improvements between 2020 and 2030 are zero or very low (<1%) for circulators, fans and most of the categories of power transformers. As a consequence, the CO_2-eq emissions reduction impact of extending the lifetime is positive for these products although it is small. However, it should be noted that this outcome is heavily dependent on the assumed efficiency improvement rate. For example, an efficiency improvement rate of 2% over 10 years would cause the CO_2-eq. emissions impacts from extending the lifetime to be negative (i.e., increasing emissions). For transformers, with an expected efficiency improvement of 9% between 2020 and 2030 due to the recent regulation, the post-2020 enforcement of the last tier and long lifetime, the impacts of an extended lifetime would clearly be negative as they would delay the positive impact of the ecodesign regulation. For more detail, including the data, hypothesis and results per product, please see Annex I.

Service economy / Improved Refurbishment

Service economy options were modelled for industrial fans, electric motors, circulators in buildings and electric pumps. Of these product groups, electric motors offered the most significant savings potential. For distribution transformers, the development of service economy type contracts was deemed unlikely. Utilities already are incentivized or obliged to improve the efficiency of the network through the Energy Efficiency Directive [OJEU, 2012] and its implementation at the Member States level. Potential impacts of a circular economy approach on these products are therefore not considered here. For more detail, including the data, hypothesis and results per product, please see Annex I.

Table 10. Overview of impacts from improved recyclability, extended service life and service economy for electric motors and related products

Motors and Motor Systems	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended Service Life, 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy no efficiency impact - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years (baseline years)				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Industrial Fans	27	22	814	10 (15)	1,713	8,566	-132	18,200
Electric Motors	89	-879	0	0 (12)	2,392	11,962	-300	57,000
Electric pumps	3	7	140	10 (11)	851	4,253	-10	1,000
Distribution and power transformers	81	-259	0	0 (32)	n.a.	n.a.	n.a.	5,000
Circulators in buildings	7	4	75	10 (10)	35	184	1	10,000

6.3. Findings of the circular economy impacts for motors and motor systems

For the options considered for motors and motor systems, the **service economy approach** seems to offer the greatest potential savings in total CO_2-eq. emissions.

The impact of improved **recyclability** on the total CO_2-eq. emissions associated with this product category represents less than 1% of the impact of ecodesign and energy labelling measures, therefore this option does not appear to be sufficiently large to warrant policy intervention.

The impact of **extended service life** varies significantly between products, and yields a negative outcome for transformers. In essence, the analysis found that any improvements of resource efficiency that would affect the efficiency of the equipment or delay the market penetration of more efficient products would tend to increase the total CO_2-eq. emissions generated by motors or motor systems. The total CO_2-eq. emissions associated with this product group represents approximately 1-2% of the impact of ecodesign and energy labelling measures, therefore this option does not appear to be sufficiently large to warrant intervention.

The impact of the **service economy** approach to these products offers between 5% (LA scenario) and 25% (BA scenario) of the emission savings of the ecodesign and energy labelling measures, and therefore represents a somewhat significant opportunity for CO_2-eq. emissions reduction for these products.

Even with the energy efficiency improvements achieved for these products over the years, the use phase still dominates the life cycle CO_2-eq. equivalent impacts of motors and motor systems. With the exception of the service economy approach, progress in the direction of a circular economy that would only affect production and end-of-life would have a relatively limited impact on the CO_2-eq. emissions associated with these products. The only improvement that follows the logic of a circular economy that could deliver significant CO_2-eq. emissions reduction is through service contracting which could include leasing of motors, an energy services type market and other approaches that would optimise the management of motors and motor systems.

7. Estimating the potential for heating and cooling products

The product category of heating and cooling products encompasses product groups such as chillers, tertiary air conditioners, central heating products, products for local room heating and room air conditioning appliances (RAC). The representative product type selected from this group for analysis was the room air conditioner.

7.1. Detailed analysis on the representative product

For heating and cooling products, the analysis centres around evaluating appropriate improvements to the equipment based on the best available information. The following circular economy aspects were analysed for this equipment in Europe, based on the aforementioned methodology:

- **Improved recyclability** –in this study, the benefit of improved recyclability was derived from the estimate found for dishwashers compared to the relative percentages of copper in dishwashers versus room air-conditioners. Copper was the main material which indicated a recyclability improvement in the various scenarios analysed by the JRC [JRC, 2015b]. The share of copper in dishwashers and room air-conditioners was derived from the respective bills-of-materials presented in the JRC study and the preparatory study on residential room conditioning appliances [Armines, 2008]. Dishwashers contain 1-2% copper and the percent improvement (in terms of CO_2-eq. emissions reduction) from better recycling is 0.50%. Room air-conditioners contain about 16% copper according to the bill of materials presented in the eco-design Preparatory Study, and the percent improvement from better recycling is therefore estimated at 6%. This is consistent with the expectation that material recovery from these products is already quite high.

- **Extended service life** – For room air conditioners, the production and end-of-life[35] represent an important share of the CO_2-eq. emissions attributed to RAC over their whole life cycle and because the largest part of efficiency improvements are expected to happen before 2020, the impact of extending the lifetime of products sold in 2020 could, according to our model, be quite significant.

- **Service economy** – an assessment of three different scenarios:
  - Limited Adoption (LA) assumes 10% of the market adopts an appliance leasing arrangement where the average life of the leased RAC would be 1.5 times longer and would have an energy consumption 5% lower than a typical (base-case) RAC unit[36]. It assumes that one repair/refurbishing/upgrading transaction would take place every

[35] The CO_2-eq. impact of the end-of-life was significantly reduced compared to the numbers of the Preparatory Study in order to account for lower GWP and better recovering of refrigerant gases.
[36] Based on data from [European Commission, 2015a].

five (5) years during the life of the leased RAC, each equivalent to 10% of the impact of initial production[37].

- Broad Adoption (BA) assumes 50% of the market adopts an appliance leasing arrangement. Average lifetime, efficiency and impact of repair/refurbishing/upgrading are kept the same as for the LA scenario. This broad adoption scenario also assumes an impact of better dismantling and recycling that would lower by 20% the impact of material extraction and end-of-life.
- **Improved refurbishment[38]** / Average efficiency (IR-BA) uses the same assumptions as BA but using the average energy consumption of 2020 sales, assuming that service economy schemes have no impact on the efficiency of the proposed/selected products.

The table below presents the results of the baseline scenario and the circular economy aspects analysed for the representative product for heating and cooling products, room air-conditioners.

[37] The impact of each reparation used to estimate the impact of extended service life is 10% of the initial impact of production and end-of-life. We made this impact quite significant here to take into account some level of refurbishment to improve efficiency throughout the lifetime, and in the case of a change of use the impact of cosmetic changes and transport.

[38] As explained in the methodology section, the environmental impacts of an improved refurbishment are considered as one aspect of what would happen by applying circular economy principles. The scenario is which circular economy is considered not to have any impact on the average initial efficiency of the appliances actually corresponds to an improved refurbishment.

Table 11. Life Cycle Assessment Impacts of the Room Air-Conditioner representative unit and Circular Economy Impacts for 2020 sales

Life cycle impacts per unit						
		Materials	Production	Use	End-of-Life	Total / unit
units		*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Business as Usual		154	100	3,622	306	4,181
Circular Economy Aspects impacts for the whole product group						
Results for 2020 RAC (2020 stock for ecodesign)		A. Benefits of CE measure	B. Life Cycle impacts of the product group	(A divided by B)	C. Benefits of ecodesign and labelling measures	(A divided by C)
units		*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(%)*	*(kt CO_2-eq.)*	*(%)*
Improved Recyclability		147	37,814	0.39%	5,000	2.94%
Extended Service Life	1 year life extension	5		0.01%		0%
	Optimal life extension	1,330		3.52%		27%
Service Economy	Estimated benefit - LA - 2020 sales	218		0.58%		4%
	Estimated benefit - BA - 2020 sales	1,369		3.62%		27%
		601		1.59%		12%

The following offers some discussion on the individual circular economy measures presented in the table above for RACs:

- **Improved recyclability** – Based on the assumption that the share of copper is a good indicator of the potential additional benefits from improved recyclability, a ratio of 6% of the CO_2-eq. emissions associated to non-use aspects will be applied for heating and cooling products. The results shown in the above table show that although non-negligible in absolute terms, the impact of better recyclability is significantly lower than the impact of ecodesign and labelling measures on the CO_2-eq. emissions associated with dishwashers.
- **Extended service life** – Extending the lifetime of RAC units by nine (9) years to reach a lifetime of 21 years is found to be the most beneficial in terms of avoided CO_2-eq. emissions. The CO_2-eq. emission reduction linked to such an extended service life is quite significant due to the relatively important impact of non-use stages in the CO_2-eq. emissions associated with the life cycle of these products, and to the fact that efficiency improvements are expected to be limited over the 2020-2030 period.

- **Service economy** – the results presented in the above table indicate that the impact of the uptake of leasing schemes on CO_2-eq. emissions from RAC could be of the same order of magnitude as the modelled extension of the lifetime. The magnitude of this impact, besides the level of adoption itself, would depend on the associated higher efficiency of the products installed under these service contracts.

Main findings of RAC Circular Economy analysis

The analysis of the circular economy options for RAC units shows that simply improving recyclability is not enough to generate significant additional CO_2-eq. emissions reduction, although there may be benefits for other environmental impacts not evaluated in this study. Extended service life could have a relatively high impact, reaching about half of the potential of the adopted Ecodesign and Energy Labelling Regulations. The service economy option also seems to offer promising improvement potential for additional CO_2-eq. emissions reduction, with the potential impact of leasing doubled if it is associated with higher efficiency units being installed through such schemes. Thus, the shift to a business model that accelerates the development of the service economy approach is an opportunity for policy makers, to influence that market shift, and trigger even more beneficial impacts (the policy framework could be designed to reward manufacturers that make their RAC units both energy efficient and long lasting).

7.2. Extrapolating the representative product to the group of products

Having prepared an estimate of the circular economy market impacts for RAC units, the next step in our analysis is to extrapolate those to the larger group of products. This extrapolation was prepared and presented for each of the circular economy options considered. Please see Annex K for detail on the data, hypothesis and results for each individual product type within the heating and cooling product category.

Improved recyclability

Improving the recyclability of a product helps to reduce the environmental impacts of the production and disposal stages. For RAC, the ratio between the impact of these stages and the benefits of the improved recyclability was estimated to be about 6%. We therefore apply this ratio to the total CO_2-eq. emissions attributed to the production and end-of-life for all the products in the heating and cooling product category, as they were presented in the ErP preparatory studies. These impact estimates are then scaled up to the 2020 sales estimates from the preparatory studies, with the assumption that the improvements will impact 50% of the local heating and cooling products and 75% of the tertiary products.

Extended Service Life / Improved Refurbishment

Extending the service life of a product yields more useful service for a given product or appliance. Large differences were observed in the net impacts of extended service life on the CO_2-eq. emissions linked to the life cycle of the products. These variations are due to differences in the rate of energy efficiency improvements and the relative share of CO_2-eq. emissions from the use stage vs. other stages. For heating products, even a limited increase of the lifetime was found to have a negative impact on CO_2-eq. emissions. In this case, Table 12 presents the results of a 1-year lifetime extension for information, but the optimal lifetime extension is noted as zero (0). Further, the benefits of prolonging the lifetime could be reconsidered in a few years, with updated information on the pace of energy efficiency improvement and the relative share of the use stage vs. other stages on the CO_2-eq. emissions.

The question of the impact of refrigerant gases warrants a specific mention. Some ErP Preparatory Studies present a high and a low impact of the end of life. In such cases, only the low impact scenario was used in our model in order to take into account the impact of the F-gas regulation. When only one scenario was presented in the ErP Preparatory Study, the impact of disposal was divided by 2.5[39] for the same reason.

Service economy

Service economy options were modelled for chillers, tertiary sector air conditioning, central heating products, local room heating products and room air conditioners. From the results of this assessment, this product category of heating and cooling products has significant contrasts. This is caused by several factors, such as:

- The impact of refrigerant gases.
- The fact that some products are reversible – i.e. can be used as heating or cooling products depending on the season. It this case, the share of the use phase in the whole life cycle is of course larger than for non-reversible products.
- The expected efficiency improvement between 2020 and 2030: from less than 4% for local heaters to over 10% for central heating and cooling products.

Although all modelled service economy scenarios appear to have positive impacts for local heating and cooling products, the potential positive impact for central heating products appears to strongly depend on the associated efficiency gain. Similar to the findings for motors and motor systems, service economy contracting for heating and cooling products, and especially central heating and cooling, could readily benefit from the type of services offered by ESCOs.

The overview of data, hypothesis and results per product lot is presented in Annex K.

[39] Factor based on the comparison between the first ErP Preparatory Study for domestic fridges and the draft Review Study.

Table 12. Overview of impacts associated to improved recyclability, extended service life and service economy for heating and cooling products.

Heating and Cooling products	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended service life, 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years (baseline years)				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Chillers	9	-17	0	0 (21)	12	72	-2	0
Tertiary Air Conditioning	2	0	10	10 (15)	0	1	-5	61,000
Central heating products (other than CHP)	4	-439	0	0 (15)	403	2,014	-9	3,700
Local room heating products	27	-591	0	0 (10)	514	2,613	115	8,400
Room air conditioning appliances	147	5	1,330	9 (12)	218	1,369	601	5,000

7.3. Findings of the circular economy impacts for heating and cooling products

For the options considered for heating and cooling products, the **service economy** approach seems to offer the greatest potential savings.

Considering the progress already made in the EU for a better management of refrigerant gases, further improving the recyclability of new heating and cooling products does not seem to represents an interesting option to lower the total CO_2-eq. emissions. The impact of the end of life of most heating and cooling products depends on the assumptions made concerning refrigerant gases and their recuperation, and significantly decreased as a consequence of the implementation of the F-gas Regulation. The impact of improved recyclability used to be very high but is therefore reducing over time for this product category.

The potential impact of **extended service life** is mainly interesting for RAC and is found to be about half of the potential impact of the ecodesign and energy labelling regulations. For the other product groups considered here under the heating and cooling product category, the total CO_2-eq. emissions impact of extending the lifetime is either very small or increasing.

Concerning the generalisation of a **service economy** approach, RAC are again the most promising product group, based on the assumptions made to build the scenarios and that are presented in Annex K. The potential for central heating products could also be relatively important but is strongly dependent on the associated energy efficiency improvement, suggesting that the type of contracts proposed by ESCOs could be the appropriate strategy for these products.

8. Estimating the potential for windows

Preparatory study work was conducted under Lot 32: Window Products, and was completed in June 2015.

As building components, windows are currently regulated by the Construction Products Regulation[40] which has resulted in product performance labels on windows [VHK, 2015]. This information has improved the information regarding product performance to the consumer / building materials specifier.

Some European regulations and directives already tackle the “ecological characteristics” of windows, such as the Energy Performance of Buildings Directive[41] – which doesn’t establish direct requirements itself, but the implementation of the Directive at the Member State level has resulted in national requirements for energy-related characteristics being adopted.

Establishing one set of consistent standards across the whole of Europe, however, has proven difficult. There are differences between roof vs. wall windows, between windows placed on a building facing South vs. those placed on the same building facing North, for windows with and without external shading, and so on. There are also important differences in window performance related to whether the surrounding environment is in a North European climate vs. a Southern one. There are, in effect, many possible combinations of criteria that establish the products envisaged to be included in LOT 32.

Windows can be made of wooden frames (a renewable material) or PVC/aluminium frames (a recyclable material), and they are easy to separate out to recover for recycling from the debris of a demolished building.

An LCA study published in 2014[42] in the USA focusing on residential households compared the restoration and replacement of windows, concluding: “[t]he results indicate that wood window restoration has less overall environmental impact when compared to a PVC and alumin[i]um-clad wood replacement window. The sensitivity analysis revealed that window lifespan assumptions impact results and demonstrates the importance of proper wood window maintenance.”

However, it does not seem practical or feasible to replace frames while re-using glass, or to replace glass while preserving frames to extend life [Personal Communication, Carsten Wachholz, EEB, 13 October 2015].

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[40] Regulation (EU) No 305/2011

[41] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings - OJ L 153, 18.6.2010, p. 13–35

[42] “Life Cycle Assessment of Residential Windows: Saving Energy with Window Restoration” by Katherine M. Switala-Elmhurst, Ph.D. Candidate, LEED AP and Philip D. Udo-Inyang, Ph.D., PE; Temple University, Philadelphia, PA.; 50th Associated Schools of Construction Annual International Conference Proceedings, 2014.

For this energy-related product group, from an ecodesign and energy-labelling perspective, it does not appear as if non-energy aspects of the LCA nor circular economy principles could be applied in any meaningful way to derive additional CO_2 emissions reduction.

9. Conclusions and next steps

Linear consumption and disposal of resources is becoming less and less sustainable as populations grow and economies expand. Shifting traditional business models towards a circular economy is essential for future generations to benefit from an innovative, robust and efficient economy. At the same time, it helps to reduce the strain on natural resources, the scarcity of which inevitably results in conflict, both now and in the future. Progressive policy leaders and business players recognise that long-term value creation involves moving away from patterns of endless consumption of materials and energy, and shifting instead toward an economy centred around recycling, reusing, repairing and providing services. In making this transition, countries will achieve savings in CO_2 emissions, as per the estimates presented in this report.

This chapter starts by providing a summary of the analytical findings presented in this report. It discusses the best opportunities for additional CO_2-eq. emissions savings derived from products and equipment covered by ecodesign and energy labelling. Next, the chapter offers potential interventions and policy options that can be applied to help accelerate a transition to these circular economy principles. Finally, the chapter discusses next steps and research opportunities to better understand and quantify the opportunities for a circular economy.

9.1. Summary of the analytical findings

The analysis presented in this study offers a first order estimate of the additional CO_2-eq. emission savings that could be expected from applying circular economy principles to products covered by Ecodesign. A high level summary of the findings for each of the product categories (*i.e.* white goods and related products, lighting, consumer electronics and related products, motors and motor systems, heating and cooling products) is presented in the Executive Summary and a more detailed overview can be found in Annex L. The estimated impact of the existing or planned ecodesign and energy labelling regulations, and the projected business as usual level of energy consumption in 2020, are also provided for reference.

Of the five product categories studied, consumer electronics emerged as the one for which the additional emissions reduction potential is the highest, particularly for improved recyclability and extended service life. Motors and motor systems, with LCAs largely dominated by the energy in use phase, would mainly benefit from adopting a service economy contracting approach - which could be offered by ESCOs or other business partners, but is still a small part of the overall market. For many of the analysed products, the potential emissions reduction associated with a service economy market scenario was linked to the assumption that leased products would be more efficient than the average. Although anecdotal evidence seems to suggest this reflects the current situation, there is no guarantee that this trend would continue if there were to be a widespread shift to a service economy. Therefore, additional incentives or requirements may be necessary to help ensure that high-efficiency products continue to be supplied to the market, even under a widespread leasing business model. A key approach could be to combine policy requirements on energy performance and extended life time, which would be facilitated by the fact that the more efficient a product is, the more likely it is to be of higher quality and longer service life. The fact that ecodesign and energy labelling requirements only apply when a product is first placed on the market in Europe is appropriate for the current business model (*i.e.* product sales economy), but these policy instruments may need to be reviewed if a service-based economy becomes main-stream and products being placed on the market are superseded by the placement of services.

Although the modelled impacts are in most cases lower than the estimated impacts of the current Ecodesign and Energy Labelling measures, it should be noted that some of the policy actions to promote circular economy principles could be introduced as adjustments to the legal framework, principles covering all products and some could be tailored to each specific product group[43]. The list of requirements presented in Annex B. Examples of Requirements in Ecolabel Criteria provides examples of requirements that are defined here for specific products but in some cases the principles could be established horizontally. If this policy approach were adopted, it would mean that one or two measures could generate very significant emissions reductions because of the very broad scope of products that would be affected by it. Moreover, this study focuses on CO_2-eq. impacts of energy related products, which were selected for their significant energy consumption during the energy in use phase; thus the impact of any measure on the efficiency in use logically remains a critical parameter. Other environmental aspects would also be impacted by the modelled improvements, yielding additional benefits. Estimating the impacts of applying circular economy principles on other environmental aspects of a product life cycle could also be a way to identify strong arguments to stimulate technology changes or alternative business models like leasing. Changes such as these would, in turn, have a positive impact on the CO_2-eq. emissions linked to these products. In addition, the potential CO_2-eq. emission impacts of applying circular economy principles to non-energy related products would also merit quantification.

This study presents estimates based on available literature and relies on the assumptions and choices made in those studies to provide a first order estimate of the potential impacts on CO_2-eq. emissions from applying circular economy principles to products covered by Ecodesign. The estimates presented here are intended as a first assessment of potential, and it is hoped that further research would be carried to further elucidate and explore these impacts. As shown in several sections of the report, there are opportunities for significant impact reductions. Details of the implementation of the circular economy principles will strongly impact the actual additional emissions reduction, as for example the efficiency of long-life products compared to the projected average. An option would be to combine policy requirements on energy performance with extended life time, knowing that the more efficient the initial product is (compared to the average), the more important it becomes to make it last (i.e., longer time to earn a return on investment, and more likely to ensure the CO_2-eq. benefits from energy in use will offset any higher emissions in the production and end-of-life stages).

[43] Commission Regulation (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment.; OJ L 339 of 18.12.2008

Table 13. Overview of estimated potential additional CO_2-eq. emissions reduction by type of improvement and product category (extended service life not taken into account for products for which it was found to increase CO_2-eq. emissions)

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended service life	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with average efficiency for service economy	Estimated impact Ecodesign and energy labelling
Products	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
White Goods and related products	71	1,762	3,138	17,014	3,023	39,600
Consumer electronics and related products	12,632	57,991	2,787	16,027	14,115	60,000
Lighting	-0.41	1,238	6,399	12,365	n.a.	38,822
Motors and Motor Systems	208	1,028	4,991	24,964	1	91,200
Heating and Cooling products	189	1,340	1,148	6,069	716	78,100

9.2. General benefits of the circular economy

Implementation of circular economy principles across Europe would require a fundamental shift in business practices and changes to the supply-chain. Widespread change like this could encounter significant opposition from the vested interests who benefit from the current economic model. However, common sense and anecdotal evidence indicate that adopting these principles at the EU level represents a great opportunity for generating economic growth, creating jobs, and reducing environmental impact. According to a study published by the Ellen McArthur Foundation, numerous studies of the impact of a circular economy have been found to be positive, offering GDP growth of 0.8-7%, adding 0.2-3% employment and reducing carbon emissions by 8-70%. [EMF, 2015]

The Toolkit for Policy makers published by the Ellen McArthur foundation evaluated the application of Circular Economy principles to a few different economic sub-sectors in the Danish economy. It found the benefits to be substantial, as described below for the construction sector in Denmark:

> *"by 2035 (2020), looping of materials could be increased to 15% (5%) by weight, resulting in 30% material cost savings (adding 5% additional labour cost). At this adoption rate, modelling suggests the construction sector could save EUR 100–130 million annually. These findings give a directional view of the magnitude of this opportunity for Denmark"*.

These estimates derived from a circular economy approach to the Danish construction sector give an indication of what could be expected for applying those same principles to other sectors and economic activity in the EU.

Potential impacts on employment should also be explored further to make sure that a broad adoption of circular economy principles would not have net negative consequences on jobs. Ernst Von Weizsäcker, Amory B. Lovins and L. Hunter Lovins addressed this issue in their 1997 publication, "Factor 4":

> *"An important element of the service economy is* 'tertiarisation of the secondary sector'*, meaning to shift emphasis in the manufacturing (secondary) sector away from production and towards consumer satisfaction by guaranteeing tailor-made products and first-class service and maintenance.*
>
> *Given the urgency of saving and creating jobs, political talent will be needed to communicate the desirability of not expanding the stock of goods. Although a stagnating stock of goods sounds like a nightmare for politicians and industrialists of today, the prospects of success in job creation and job-savings are actually not that bad.*
>
> *(…)*

For the North, worried by floods of cheap and short-lived consumer goods from the South, the service economy may bring some relief with regard to jobs. Maintenance, repair and re-manufacturing of and financial services for autos used in the US or Europe will, as a rule, be done in the region, much of it in town, even if the car itself may come from Korea or Mexico. We believe that appreciably more jobs will be saved or created by moving actively towards the service economy than by a laissez-faire continuation of the old industrial paradigm. (…)"

9.3. Implementation Options

At a recent study group of circular economy experts,[44] three general implementation themes emerged around which the principles of a circular economy could be promoted in Europe. The three general themes are:

- **Communications** - a positive narrative on the benefits derived from new business models and the redesign of products, targeting a wide range of stakeholders from industry to consumer groups;
- **Regulations** – developing and revising product policy regulations to include circular economy principles and supporting new business opportunities through Ecodesign, Energy Labelling, Extended Producer Responsibility, etc.; and
- **Incentives** – the removal of barriers that slow the uptake of circular economy principles and prevent adoption of new business models

Communications

New marketing and communications approaches would be a core element of a campaign to change how people engage with the circular economy. The study group felt that a new, positive narrative should be developed which is more people-oriented and focused on values, good design and quality. This vision for improving communications could be based around three components: (1) product design, (2) business models, and (3) new business players, including aggregators and innovators.

The study group felt that the wider social benefits should be highlighted, such as local jobs, safety of the people, and so-on. It was suggested that organisations such as consumer groups and health charities may be good vehicles to carry these messages, in part because of their strong constituency.

The group also felt that the circular economy approach would be adopted more easily if clear business cases were developed and communicated to the market. Contrasting this approach with vague appeals to promote circular economy which have focused on environmental sustainability, the group highlighted the fact that in a changed business context, companies will have to adopt a new

[44] The European Climate Foundation convened a focused study group in March 2016 in The Hague to discuss circular economy principles and potential implementation measures. The implementation recommendations of that meeting are summarised in this subsection.

mind-set and innovate. That degree of change is only realistic when robust business cases are developed and clearly communicated to entrepreneurs and progressive business leaders.

Regulations

From a policy perspective, the leadership in Brussels and at the national level across Europe need to ask themselves 'what type of regulation will send clear signals to the companies and incentivise them to fundamentally change their business models?' Fortunately, there are regulatory mechanisms already in place in Europe which can be applied to help promote the circular economy. The ecodesign directive already takes life-cycle assessment into account, and as quantified in the findings of this study, could be further applied to help deliver additional CO_2 savings and the wider environmental, economic and social benefits described in the literature [EMF, 2015].

To date, the focus of ecodesign has been energy-in-use, because this has been the area of the impact that offers the greatest opportunity for cost-effective improvement. And now, as efficiency levels increase, other aspects of the product life-cycle become relatively more important, which makes the opportunity for impact through the circular economy even more compelling. In addition to ecodesign, a market-push mechanism, the energy labelling directive helps to pull markets towards more environmentally sustainable products. This mechanism, coupled with extended producer responsibility could be applied to help enhance and extend the impact on products.

At a national level, countries could establish special economic zones, as seen in the Netherlands and in China, as a means of finding which regulatory policies are most effective at stimulating the market and facilitating the transition to the circular economy. Furthermore, the inclusion modulated fees as suggested in article 8a 4(b) of the extended producer responsibility scheme would be a positive step towards promoting better performance and transparency of the various national EPR systems. It would promote reusability and recyclability of individual products/ groups of products might be an extra incentive to improve design for recycling.

Incentives

There are many options available to policy-makers which are not regulatory, but which can be applied to help encourage and slowly / smoothly transition markets towards a circular economy and more eco-effective products. The following list provides a few of these incentive schemes:

- **Green public procurement** – defining the specification of products and services that will be procured by public bodies which incorporate aspects of the circular economy, and potentially giving preference to companies that amend their operating procedures (e.g., the Prorail CO_2 performance scheme whereby companies receive an advantage in procurement procedures if they perform better than their competition on some environmental aspects);

- **Green corporate procurement** – encouraging large corporations to adopt the green public procurement specifications into their own procurement practices (e.g., a kind of "Circular Economy Partners" initiative);
- **Adjusting taxes on resources vs. labour** – some aspects of the service economy such as repair, maintenance and refurbishment of appliances can be more demanding than the current linear dominant model in terms human resources. This is a barrier that makes it more challenging for companies to develop a profitable business model based on services than based on products. Additionally, with mass production of appliances, buying an appliance no longer is as a major investment as it once was – in fact, repairing an old one can be more expensive than buying a new one. Furthermore, with rapid obsolescence, consumers may be worried that they would invest in repairing a machine that may be likely to rapidly fail again. For all these reasons, a tax shift seems essential to moving towards a more circular economy, lowering taxes on labour and increasing taxes on the consumption of non-renewable resources, as recommended by the Club of Rome [Club of Rome, 2015].
- **Tax rebates** – as one of the leading mechanisms of control of any government over businesses operating in its economy, offering tax holidays, tax breaks and other tax incentives to promote Circular Economy practices;
- **Feed-in tariffs** – establishing mechanisms that recognise and directly reward practices such as feed-in tariffs which for example have enabled the development of virtual power plants in Germany through performance guarantees, and which have been instrumental in the success of the Energiesprong model, whereby renovations of social housing include the replacement of all household appliances with the most efficient ones;
- **Green financing mechanisms** – establishing low- or zero-interest financing for companies that need capital in order to develop and implement the business plan (note: this financing mechanism could also include a free circular economy business consulting service);
- **Voluntary labelling schemes** – establish new (or adapt existing) labelling schemes to take into account and reward principles of the circular economy; and
- **University design competitions** – recognising that major change will have to come the next generation of innovators and researchers, establish corporate-sponsored design competitions for products that incorporate the principles of efficiency, repair, reuse and disassembly for recycling (e.g., Xeros bead-based washing machines with order-of-magnitude lower water and energy footprint).

9.4. Next steps and areas for further research

This study has found that the magnitude of the emissions reduction potential associated with the application of circular economy principles is, for some products, of the same order of magnitude and potentially (depending on actual adoption of schemes, extension of lifetime, etc.) even higher than the emissions reduction from ecodesign and energy labelling measures. It is, however, only a first step towards understanding the emissions reduction opportunity and supporting appropriate policy action.

The study is also intended to help guide future areas of research around principles of a circular economy. Some of the ideas for follow-on research in this area are suggested below::

- **Economic assessment** - an evaluation of the economic requirements and potential impacts of applying the principles of a circular economy broadly across Europe, including e.g., a cost-benefit analysis, return on investment, financing mechanisms, etc.;
- **Accounting standards** – the development of new financial and accounting standards and metrics that capture the full benefits of energy-efficiency and the circular economy;
- **Product metrics** – the development and improvement of metrics to assess whether a product is eco-effective and eco-efficient or not; enabling companies, governments and consumers to identify eco-efficient products;
- **Plastics recycling industry** – conduct market research and develop policy measures designed to stimulate and support the development of a larger and more robust plastics recycling industry in Europe;
- **Best opportunity focus: products** – conduct a more in depth analysis to explore the improvement potential for specific products which offer the greatest greenhouse gas saving potential, and contribution to the ecodesign work plan;
- **Best opportunity focus**: **improvements** – conduct a more in depth analysis to explore the improvement potential for specific improvements which offer the greatest greenhouse gas saving potential. This could cover a product per product analysis of what lifetime extension would be realistic; investigate the upgrading potential of some products, and their modularity. These options are believed to have very significant potential for consumer electronics in particular.
- **Policy measure study** - a research study on potential and appropriate policy mechanisms to encourage a market transition to a circular economy, looking at incentives as well as voluntary and regulatory policy measures;
- **Focus on energy-related products** - a scoping study for products that are related to energy use (e.g., windows or insulation - non energy using products); and
- **Shared resources** - an evaluation of the potential savings and socio-economic benefits that could be achieved via policy incentives toward a sharing economy in relation to certain ecodesign products (e.g., super-efficient washing machines and tumble driers, game consoles, printers). The scenarios developed for leasing in this study result in saving estimates that are comparable to what could happen when sharing resources (potentially more efficient products, less production and End-of-Life impacts for a same provision of services). Sharing would however not be possible for all products (not for lighting or for Commercial Refrigeration Equipment, for example). Moreover, very little literature could be found about the potential level of adoption of sharing as opposed to owning, or how many potential owners would share the equipment at the same time. These estimates would have to be very product specific.

In the coming years, the community of stakeholders working on circular economy will continue its work to establish and implement a policy framework that supports the redesign of appliances and promotes the uptake of new business models that capture the full decarbonisation and circularity potential of appliances. On-going research, exchanges with experts and engagement with industry will all help to support the overall objective of establishing a comprehensive circular economy in Europe.

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- ENER Lot 25 - Non-tertiary coffee machines, Preparatory study
- ENER Lot 28/29 - Pumps (other than Lot 11), Preparatory study
- ENER Lot 30 - Other electric motors (outside Regulation 640/2009)
- ENER Lot 31 - Compressors (outside Regulation 640/2009), , Preparatory study
- ENTR Lot 1 - Refrigerating and freezing equipment, Preparatory study
- ENTR Lot 2 - Distribution and power transformers, Preparatory study
- ENTR Lot 3 - Sound and imaging equipment, Preparatory study
- ENTR Lot 6 - Tertiary ventilation, Preparatory study

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ANNEXES

Annex A. List of Products per Cluster

Products from the Ecodesign Implementing Measures	Heating and cooling	Lighting	Electronics & related	White Goods & related	Motors and systems	Not covered	Approach and Reference product
Room air conditioning appliances: 206/2012 and 626/2011 (Lot 10)	x						Reference Product: Room Air Conditioners No technology shift was modelled. Where several technologies or types of installations can deliver the same service we have maintained the balance of technologies projected in the Ecodesign Impact Accounting study..
Local room heating products, Lot 20	x						
Central heating products (other than CHP), Lot 21	x						
Tertiary Air Conditioning: 1253/2014 (ENTR Lot 6)	x						
Tertiary Lighting: 245/2009 (Lot 8-9)		x					Modelling the consequences of a complete shift to LED. LED is the future, and could have been pushed harder into the current market.
Domestic lighting (general lighting equipment):244/2009 and 874/2012 (Lot 19)		x					
Directional lighting: 1194/2012 and 874/2012 (Lot 18)		x					

Products from the Ecodesign Implementing Measures	Heating and cooling	Lighting	Electronics & related	White Goods & related	Motors and systems	Not covered	Reference product and rationale
PC:s and servers: 617/2013 (Lot 3)			x				Reference Product: LCD screens and IJ printers for recyclability, notebook for durability and service economy.
Imaging equipment, Voluntary agreement (Lot 4)			x				
Smart Phones			x				The impact of a complete shift to LED was modelled for TVs and computer monitors.
Enterprise servers, ENTR Lot 9			x				
Televisions: 642/2009 and 1062/2010 (Lot 5)			x				Smart phones were added to the analysis based on the information available in the study for the third ecodesign Working Plan and other literature focusing on LCA.
Complex set-top boxes (Lot 18)			x				
Simple set-top boxes: 107/2009 (Lot 18)			x				Battery chargers and external power supplies were not analysed because like for all accessories sold with consumer electronics, more than their durability or the possibility to lease them, or improving their design for a better recyclability, the potential in terms of resource efficiency seems to be in changing the current model of including all accessories in each package making consumers pay for materials they never wanted.
Sound and imaging equipment, ENTR Lot 3			x				
Battery chargers and external power supplies: 278/2009 (Lot 7)						x	
Medical imaging equipment						x	

Products from the Ecodesign Implementing Measures	Heating and cooling	Lighting	Electronics & related	White Goods & related	Motors and systems	Not covered	Reference product and rationale
Commercial refrigerators and freezers, Lot 12				x			Reference Product: Dishwashers
Domestic refrigerators and freezers: 643/2009 and 1060/2010 (Lot 13)				x			
Domestic washing machines: 1015/2010 and 1061/2010 (Lot 14)				x			
Domestic dishwashers: 1016/2010 and 1059/2010 (Lot 14)				x			
Laundry driers: 813/2013 and 392/201 (Lot 16)				x			
Vacuum cleaners: 666/2013 and 665/2013 (Lot 17)				x			
Kitchen appliances: 65/2014 and 66/2014 (Lot 22 and 23)				x			
Professional wet appliances and dryers, Lot 24				x			
Non-tertiary coffee machines, reg. 801/2013 (Lot 25)				x			
Refrigerating and freezing equipment, ENTR Lot 1				x			

Products from the Ecodesign Implementing Measures	Heating and cooling	Lighting	Electronics & related	White Goods & related	Motors and systems	Not covered	Reference product and rationale
Distribution and power transformers: 548/2014 (ENTR Lot 2)					x		Reference Product: Electric Motors This product category consists of electric motors and systems designed around an electric motor which they use to provide a service such as moving air, water, etc. Distribution transformers use many of the same materials as electric motors, and thus design improvements in terms of wire and core steel will be common to both product groups. The level of detail available for residential ventilation did not allow us to cover this lot in our analysis. Power Cables and lots 28 to 31 were not covered by the study due to the lack of available projections and the little expected potential of these products (conclusions for the rest of the products of this category would certainly apply to these products)
Power cables, ENTR Lot 8					x		
Residential ventilation: 1253/2014 and 1254/2014 (Lot 10)						x	
Ventilation fans: 327/2011 (Lot 11)					x		
Electric motors: 640/2009 and 4/2014 (Lot 11)					x		
Circulators in buildings: 641/2009 (Lot 11)					x		
Electric pumps , Lot 11					x		
Pumps for waste waters, Lot 28					x		
Large pumps and pumps for pools, fountains, aquariums, Lot 29					x		
Special motors and variable speed drives, Lot 30					x		
Compressors, Lot 31					x		

Ecodesign Implementing Measure Products	Heating and cooling	Lighting	Consumer Electronics & assimilated	White Goods & assimilated	Motors, motor systems & assimilated	Not covered	Reference product and rationale
Space and combination heaters: 813/2013 and 811/2013 (Lot 1)						x (fuel issue)	Not considered - The impact of potential improvement on resource efficiency is expected to be quite limited for these products and the discussion would be complex and political - due to the different fuel options and their impact on direct and indirect CO_2 emissions (which would depend on the electricity mix for each country, projections, etc.).
Water heaters: 814/2013 and 812/2013 (Lot 2)						x (fuel issue)	
Solid fuel boilers, Lot 15						x	
Steam boilers: ENTR Lot 7						x	
Standby and off-mode losses: 1275/2008 (Lot 6)							Horizontal lots
Networked standby losses, reg. 801/2013 (Lot 26)							
Machine tools, ENTR Lot 5						x	These Lots would have to be covered individually.
Window products, ENER Lot 1/03						x	
Taps and shower heads, JRC						x	
Industrial ovens, ENTR Lot 4						x	

Annex B. Examples of Requirements in Ecolabel Criteria

Table 14. Examples of requirements in Ecolabel criteria for ErP product groups

		Criteria about . . .						
Product Group	**Criteria Date**	**Reusability**	**Recyclability**	**Recoverability**	**Recycled Content**	**Use of Priority Resources**	**Use of Hazardous Substances**	**Extended Service Life**
Personal Computers Portable Computers	09/06/2011 06/06/2011	Design for disassembly: "The manufacturer shall demonstrate that the personal computer/monitor can be easily dismantled by professionally trained personnel using the tools usually available to them, for the purpose of undertaking repairs and replacements of worn out parts, upgrading older or obsolete parts, and separating parts and materials, ultimately for recycling or reuse.			The external plastic case of the system unit, monitor and keyboard shall have a postconsumer recycled content of not less than 10 % by mass. Criteria on recycled content into packaging	circuit boards, and/or other precious metal containing components, shall be easily removable using manual separation	Exclusion of dangerous substances in the product (mercury and other hazardous substances)	Design for Disassembly; User reparability (instruction for the users for basic repairs); spare parts are available for at least five years from the selling, Lifetime extension (upgradability)
Televisions	12/03/2009	-	Manufacturer shall demonstrate that the television can be easily dismantled [...] for the purpose of: undertaking repairs and replacements of worn-out parts, upgrading older or obsolete parts, and separating parts and materials, ultimately for recycling.		-	-	Data on the nature and amount of hazardous substances in the television shall be gathered in accordance with Directive 2006/121/EC	Life-time extension (extended warranty for 2 years and availability of spare parts for 7 years)
		-	Plastic parts shall be of one polymer or be of compatible polymers for recycling and have the relevant ISO11469 marking if greater than 25 g in mass		-	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
Light Bulbs	06/06/2011	-	-	-	Criteria on the recycled content of packaging	-	Restricted use of mercury and other hazardous substances	Criteria on minimum lifetime and lumen maintenance factor. Criteria on minimum number of switch on/off cycles.

Criteria about . . .								
Product Group	Criteria Date	Reusability	Recyclability	Recoverability	Recycled Content	Use of Priority Resources	Use of Hazardous Substances	Extended Service Life
Heat Pumps	09/11/2007	-	-	-	-	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases. Criteria about the impacts of refrigerants	Information for the maintenance and availability of spare parts
Lubricants	24/06/2011	-	-	-	-	-	Restrictions on the use of several hazardous substances; tests on the toxicity of the substances	-

Source: [JRC, 2012]

Annex C. Data Quality Assessment and Limitations of the Study

This annex considers the quality of the data underpinning the analysis. A broad range of products and of aspects was covered in this study, and many assumptions were made to build the scenarios.

Several experts on LCAs, resource efficiency and European environmental policy tools contributed to and reviewed the study. These reviews helped us adjust some of the input data and assumptions, and improve the overall quantification of the CO_2-eq. emissions reduction derived from principles of a circular economy. The feedback from reviewers indicated that the data and assumptions used in this study are reasonable and appropriate to elaborate the first order estimates that this study is aiming to provide. However, there are also limitations to the analysis that could be carried out for this study, and this annex attempts to identify the main potential issues and explain the choices that were made. The recommendations for future work identified in the report propose ways to improve the analysis in particular for what are identified as priority products and approaches.

General scope of the study

This study deliberately focuses only on CO_2-eq. emissions, ignoring other environmental aspects. This choice was made because (1) it aligned with CLASP work over the last 7 years in Brussels supporting the Commission's policy-making process; and (2) energy in use (and thus, CO_2 emissions) have always been the focus of ecodesign and energy labelling, and this study relies on some of the literature published around these policy instruments. This decision not to consider other environmental aspects should not be interpreted as indicating that these other aspects are less important or should not be evaluated, but is more a reflection of the aforementioned reasons and simply that there was a need to focus on one aspect.

Input data

Input Issue #1 - Life Cycle Assessment data

- Quality of the LCA data in the ErP Preparatory Studies

The potential data quality issue mentioned frequently in the expert peer review was the fact that ErP Preparatory Studies may under-estimate the impact of the life-cycle stages other than use stage. This concern has been published (see for example [Oko Institut, 2012]). For nearly all products, the choice was made to use the data from the ErP Preparatory Studies, since this ensures the best possible homogeneity of the methodology and geographical coverage. Also, using these sources offers excellent geographical coverage and technology coverage across Europe. It also ensures that the analysis is based on products that are actually covered by ecodesign and labelling regulations, and for which there is peer-reviewed sales and performance information.

In order to assess the potential impact of an under-estimate of the impacts in non-use life-cycle stages, the approach followed was to test a +30% increase of these impacts. The results of this additional sensitivity analysis are presented in Annex N. All other data and assumptions are kept the same and only the CO_2-eq. emissions associated with production and end-of-life were increased by 30% compared to the values presented elsewhere in the report. See Annex N for a discussion of these findings.

- Other sources

For products or technologies not covered by an ErP Preparatory Study (*e.g.*, smart phones, LED displays), several data sources were analysed and wherever possible, analytical choices and estimates were made to be as representative as possible while ensuring the analysis is consistent with the data presented in the ErP Preparatory Studies.

- Future validity of analytical findings

The analysis conducted today and used to predict benefits of measures in the future is in fact a 'moving target'. There are forecasts available, but scarcity of materials in the future and life-cycle assessment impacts associated with different stages can (and will) change over time. Thus, the analysis conducted today may quantify the environmental impact reductions from recycling, but these reductions could be under estimated if there is a resource scarcity situation, or a significant change in the environmental impacts from mining.

- Interaction between policies and product design

There is a complex interaction between policies/requirements and the design and impacts of products. For example, if requirements enter into force that aim at improving the service life of products, manufacturers may decide to change the material used in some components. Thus, the LCA used in the analysis presented in this report may have evolved more or less significantly in response to policy action, which in turn would affect (positively or negatively) the potential emissions reduction associated to the application of some circular economy principles.

Input Issue #2 – Efficiency projections
Efficiency improvement over time will strongly depend on the ambition of Ecodesign and Energy Labelling Regulations and revisions. Some results of the modelled scenarios strongly depend on these estimated forecasts of efficiency improvement. For these data, we used forecasts from the European Commission [European Commission, 2015a], as well as recent ErP Preparatory or Review Studies and/or Impact Assessments. We worked to ensure the most realistic efficiency projections possible.

Furthermore, it will likely become increasingly difficult to maintain a high pace of efficiency improvement for many more years. The analysis should therefore be revised periodically in order to update the efficiency baseline and projections. The estimated impact of extending the lifetime will significantly evolve over time as the pace of efficiency improvement diminishes, and extending lifetime becomes more beneficial (in terms of total CO_2-eq. emissions) for more and more products.

<u>**Assumptions**</u>

Assumptions Issue #1 – Assumptions on the impact of the potential evolution of the design
If requirements or incentives are put in place to improve recyclability, refurbishability, or extended service life of products, this may affect the design of the concerned products, which will affect the LCA. This level of detail was not taken into account in the analysis as it would have required in-depth research and data for each product. This could however be the subject of a future research study, and/or LCA.

Assumptions Issue #2 – Assumptions on improved recyclability
Similarly, if requirements or incentives are put in place to improve recyclability of products, this may affect the whole sector, from product design to the recycling processes or the number of recycling facilities. Based on the findings of the JRC studies (see for example [JRC, 2015a]), the scenarios presented in this study are based on a limited increase of the share of recycled materials for each product, but apply this increase to a large share of the products.

Assumptions Issue #3 – Assumptions for the service economy scenarios
No one can predict how common the service economy contracts will be in a few years, or whether entire sectors could be impacted by a broad adoption. The intention here was therefore to describe different scenarios and their impacts in a transparent way in order to present a range rather than only one figure.

Product specific

Product Issue #1 – Modelling of Zhaga Consortium Standards on Lighting Sector

The Zhaga Consortium (http://www.zhagastandard.org/) is a voluntary organisation which works to establish design standards that enable the interoperability of LED light modules in LED luminaires. Zhaga prepares 'books' that carefully detail a design standard giving the light output, optical characteristics, and the thermal and electrical connections for a given LED light module. These modules are then designed to fit in LED luminaires, enabling the modules to be replaced in the future, without having to replace the rest of the luminaire or driver. Furthermore, the LED light modules can take advantage of the improving efficacy of LED lamps over time, as the design spec is set, so new modules will be introduced into the market in the future which have the same performance but simply use less power. This type of approach to lighting already exists in certain niche applications in the market, such as in LED street lighting (note: Zhaga has 13 different 'books' published which define standards for a range of luminaires). The Zhaga standards closely resemble the circular economy principle of "improved refurbishment", as it is designed to allow for future upgrades as LED technology continues to evolve. However, there is limited data available on the take-up of Zhaga standards in the market, and LCA analysis data to begin to quantify the lifecycle benefit of adopting a modular light engine approach to LED luminaire design. Therefore, this option was not included in the analysis of the lighting sector, but could constitute a topic of interest for future assessment in the context of the circular economy and improved refurbishment.

Annex D. LCA for White Goods and literature review

Table 15. Life Cycle Assessment for White Goods

Average impacts per unit:	Material	Manuf.	Distrib.	Use	Use 2020	Disposal	Recycle	Total Life Cycle (in 2020)
	(kg CO_2-eq.)	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Dishwasher	140	13	-	1,700	1,496	6	-	1,655
Tumble drier	83	34	34	1,959	1,556	17	-14	1,710
Washing machine	244	-	-	958	628	10	-	881
Domestic refrigerators and freezers	183	59	61	1,896	1,291	34	-85	1,543
Vacuum cleaners	23	12	9	356	195	22	-8	253
Kitchen appliances	58	9	18	1,626	1,487	12	-0	1,584
Non-tertiary coffee machines	14	5	7	430	352	10	-7	381
Professional wet appliances and dryers	852	146	87	53,531	43,901	95	-78	45,002
Professional refrigerating equipment	2,041	251	330	53,064	44,531	3,138	-156	50,134
Commercial refrigerators and freezers	826	154	177	22,567	18,938	144	-20	20,219

Sources: Ecodesign Preparatory Studies; Integration of resource efficiency and waste management criteria in European product policies - Second phase, Report n° 2, JRC, 2012 (WM); Environmental Footprint and Material Efficiency Support for Product Policy, JRC, 2015 (DW)

The analysis of the potential for dishwashers presented in the report relies mainly on the methodology and data presented in [JRC, 2015a]. This technical report analyses and compares several sources, including the ecodesign Preparatory Study, for all phases of the life cycle of a dishwasher.

The CO_2-eq. emissions associated to each life cycle stage as used in the JRC study are presented in the following table:

Table 16. Dishwasher LCA used in [JRC, 2015a])

	Materials	Manufacturing	Use	Disposal	Total per product
units	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
CO_2-eq. emissions	140	13	1700	6	1860

For comparison, the ErP Preparatory Study gives the following values:

Table 17. Dishwasher LCA used in [ENEA, 2007])

	Material	Manufacturing	Distribution	Use	Disposal	Recycle	Total per product
units	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Global Warming Potential	222	48	37	1519	15	15	1825

We observe that the share of the sum of production and end-of-life phases is higher in the preparatory study than in [JRC, 2015] (14.8% vs. 8.6%).

Additionally to the information gathered from the literature for dishwashers that is presented in the report, estimates were gathered from various sources for some improvements applied to some other white appliances and related products.

Washing Machines

[JRC, 2012b] analyses the potential impacts of requirements on disassemblability of PCBs, disassemblability of LCD screens, and motor disassembly.

The benefits related to the disassembly of LCD screens could not be quantified. The benefits relative to the disassemble of circuit boards and motors were estimated to 16,100 Mt CO_2-eq. and 6,350 Mt CO_2-eq. respectively, for the whole product group, with the hypothesis that only 50% of washing machines will beneficiate of such requirements. The sales estimate used in [JRC, 2012b] for this calculation is 20.7 millions of units per year, of which 60% belong to the medium-low price typology and 40% to the medium-high price typology. These estimates were used for the calculation of the impact of improved recyclability as presented in the report.

Refrigerators

[Ricardo-AEA, 2015] shows that increasing the lifetime of refrigerator-freezers is not likely to be reduce the CO_2-eq. emissions associated with these products. Indeed, depending on the source of data used (the study tests two different models), the threshold of energy efficiency improvement (after 10 years) above which there is no benefit in extending the lifetime of a fridge-freezer is between 5 and 10%.

The report notes that “It is very encouraging that the two analyses reach essentially the same conclusion, and hence support each other. Even though the Ecodesign Preparatory Study data is now relatively dated, the fact that the very recent manufacturer data also generates the same result gives confidence in the approach adopted.”

If we consider products sold in 2020, the average energy efficiency improvement to be expected from a replacement product after 10 years should, according to extrapolations from the ecodesign Preparatory Study for domestic refrigerators and freezers[45], be above 25%[46]. Even in absolute value this level of improvement represents more TWh/tCO_2-eq. per year than 5-10% of the consumption of current products. We therefore do not consider that it would be beneficial from the point of view of CO_2-eq. emissions to extend the lifetime of domestic refrigerator and freezers. This conclusion is supported by our application of the REAPro methodology for durability (i.e., extending the service life) to the case of domestic refrigerators and freezers, using information from the preparatory studies.

[45] DG Energy, personal communication, October 2015
[46] The evolution of the best available technology can be expected to be more limited, but the figure presented here reflects the evolution of the average efficiency of the sales according to [European Commission, 2015a]

Ovens

[Ricardo-AEA, 2015] presents two models to evaluate the potential impact of increasing the lifetime of electric ovens. Both models conclude to a negative impact of a 5-year extension of the lifetime, concerning the total emissions of CO_2 Eq. This conclusion is supported by our application of the JRC methodology for durability (i.e., extended service life) to the case of electric ovens and other kitchen appliances covered by the ecodesign lots 22 and 23, Household and commercial ovens and Household and commercial hobs and grills.

Annex E. Main parameters and results for White goods and related products

Table 18. Improved Recyclability Impacts for White Goods

Product	Impact of production +end-of-life per unit	Estimated impact of improved recyclability per unit	Sales in 2020	Estimated impact of improved recyclability for 2020 sales
Units:	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(million units)*	*(t CO_2-eq.)*
Dishwasher	159	0.7	9,233	3.430
Tumble drier	154	0.8	5,902	2.269
Washing machine	254	2.1	14,081	14.965
Domestic refrigerators and freezers	252	1.3	19,700	12.396
Vacuum cleaners	58	0.3	91,611	10.641
Kitchen appliances	97	0.5	32,157	7.819
Non-tertiary coffee machines	29	0.1	27,229	1.590
Professional wet appliances and dryers	1,101	5.5	391	1.614
Professional refrigerating equipment	5,603	28.0	735	10.293
Commercial refrigerators and freezers	1,281	6.4	1,786	5.720

Table 19. Extended Service Life Impacts for White Goods

Product	Lifetime Basecase	Extension of lifetime	Associated energy consumption of replacement	Benefit/unit	Benefit 2020 sales	Benefit/unit for 1 year additional lifetime	Benefit 2020 sales for 1 year additional lifetime
Units:	*(years)*	*(years)*	*(% of initial)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*
Dishwasher	15	-	74%	1	0	-23	-208
Tumble drier	13	-	78%	1	0	-25	-145
Washing machine	15	-	65%	0	0	-19	-267
Domestic refrigerators and freezers	16	-	57%	1	0	-38	-742
Vacuum cleaners	6	6	77%	19	1,762	3	301
Kitchen appliances	17	-	86%	1	0	-13	-421
Non-tertiary coffee machines	6	-	91%	1	0	-2	-60
Professional wet appliances and dryers	10	-	82%	1	0	-820	-320
Professional refrigerating equipment	10	-	92%	1	0	-123	-90
Commercial refrigerators and freezers	8	-	93%	1	0	-92	-165

Table 20. Service Economy Impacts for White Goods

Product	Efficiency improvement leased products	Low adoption rate	High adoption rate	Factor lifetime low adoption rate	Factor lifetime high adoption rate	Refurbish-ment % non-use aspects	Impact of better dismantling and recycling HAR	Benefit 2020 sales LAR	Benefit 2020 sales HAR	Benefit 2020 sales HAR
Units:	*(%)*	*(%)*	*(%)*			*(%)*	*(% of material and EoL)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Dishwasher	18%	10%	50%	1.5	1.5	10%	20%	227	1,225	123
Tumble drier	17%	10%	50%	1.5	1.5	10%	20%	165	858	71
Washing machine	24%	10%	50%	1.5	1.5	10%	20%	257	1,525	327
Domestic refrigerators and freezers	27%	10%	50%	1.5	1.5	10%	20%	750	3,921	144
Vacuum cleaners	12%	10%	50%	1.5	1.5	10%	20%	308	1,766	1,014
Kitchen appliances	9%	10%	50%	1.5	1.5	10%	20%	425	2,277	116
Non-tertiary coffee machines	9%	10%	50%	1.5	1.5	10%	20%	94	502	147
Professional wet appliances and dryers	18%	10%	50%	1.5	1.5	10%	20%	296	1,504	65
Professional refrigerating equipment	8%	10%	50%	1.5	1.5	10%	20%	340	1,948	634
Commercial refrigerators and freezers	7%	10%	50%	1.5	1.5	10%	20%	275	1,487	382

Annex F. LCA for Consumer electronics and related products

Table 21. LCA for Consumer Electronics and related Products

Average impacts per unit:	Material	Manuf.	Distrib.	Use	Use 2020	Disposal	Recycle	Total Life Cycle (in 2020)
	(kg CO_2-eq.)	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Televisions	241	55	50	511	163	50	-47	513
Computer monitors	84	19	18	261	130	18	-17	254
Simple set-top boxes	18	4	8	250	199	3	-3	229
Complex set-top boxes	31	8	9	419	322	9	-5	374
Video	12	3	10	95	95	9	-1	128
Game consoles	54	11	12	105	155	22	-5	249
Computer servers	1,828	136	26	29,971	13,940	-	-918	15,013
Personal computers	54	95	22	113	46	5	-2	220
Smart phone	5	31	5	9	9	1	-	51
Imaging equipment	104	22	4	190	83	57	-12	259

Sources: Ecodesign Preparatory Studies; Integration of resource efficiency and waste management criteria in European product policies - Second phase, Report n° 2, JRC, 2012 (IJ Printer); Environmental Footprint and Material Efficiency Support for product policy, JRC, 2015 (rack servers); Life Cycle Assessment of CRT, LCD and LED Monitors, Vikrant Bhakar & al. , 2015; From Smartphone to Futurephone, assessing the environmental impacts of different circular economy scenarios of a smartphone using LCA, M. Güvendik, 2014, Global Warming Potential of a Smartphone, Using Life Cycle Assessment Methodology, Elif Mine Ercan, 2013.

Annex G. Main parameters and results for Consumer electronics and related products

Table 22. Improved Recyclability Impacts for Consumer Electronics

Product	Impact of production +end-of-life per unit	Estimated impact of improved recyclability per unit	Sales in 2020	Estimated impact of improved recyclability for 2020 sales
Units	*(kg CO2-eq.)*	*(kg CO2-eq.)*	*(million units)*	*(t CO2-eq.)*
Televisions	350	102	72,710	6,316
Computer monitor	126	37	20,000	623
Simple set-top boxes	30	5	0	0
Complex set-top boxes	52	9	43,897	330
Video	33	6	28,460	136
Game consoles	94	16	11,000	149
Computer servers	1,073	182	1,800	279
Personal computers	183	31	130,000	3,437
Smart phones	42	7	155,820	942
Imaging equipment	171	19	25,685	419

Table 23. Lifetime extension impacts for Consumer Electronics

Product	Lifetime (in use)	Extension of lifetime	Associated energy consumption of replacement	Benefit/unit	Benefit 2020 sales	Benefit/unit for 1 year additional lifetime	Benefit 2020 sales for 1 year additional lifetime
Units	*(years)*	*(years)*	*(% of initial)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*
Televisions	7	7	96%	323	23,518	32	2,307
Computer monitors	7	7	70%	90	1,808	8	167
Simple set-top boxes	5	5	100%	29	0	5	0
Complex set-top boxes	4	4	94%	27	1,180	7	315
Video	5	5	100%	32	897	5	142
Game consoles	6	6	133%	136	1,495	16	175
Computer servers	5	-	83%	1	0	-397	-714
Personal computers	4	4	73%	155	20,202	33	4,343
Smart phones	3	3	100%	31	4,887	15	2,281
Imaging equipment	4	4	96%	156	4,003	33	853

Table 24. Service Economy Impacts for Consumer Electronics

Product	Efficiency improvement leased products	Low adoption rate	High adoption rate	Factor lifetime low adoption rate	Factor lifetime high adoption rate	Refurbishment % non-use aspects	20%	Benefit 2020 sales LAR	Benefit 2020 sales HAR	Benefit 2020 sales HAR
Units	*(%)*	*(%)*	*(%)*			*(%)*	*(%)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Televisions	0%	10%	50%	1.5	1.5	2%	20%	812	5,241	5,740
Computer monitors	21%	10%	50%	1.5	1.5	2%	20%	121	719	565
Simple set-top boxes	0%	10%	50%	1.5	1.5	10%	20%	0	0	0
Complex set-top boxes	3%	10%	50%	1.5	1.5	10%	20%	117	686	511
Video	0%	10%	50%	1.5	1.5	10%	20%	28	179	190
Game consoles	-17%	10%	50%	1.5	1.5	10%	20%	1	55	209
Computer servers	17%	10%	50%	1.5	1.5	10%	20%	476	2,490	437
Personal computers	13%	10%	50%	1.5	1.5	10%	20%	857	4,864	4,571
Smart phones	0%	10%	50%	1.5	1.5	10%	20%	228	1,204	1,263
Imaging equipment	2%	10%	30%	1.5	1.5	10%	20%	148	588	628

Annex H. LCA for Motors and Motor Systems

Table 25. LCA for Motors and Motor systems

Average impacts per unit:	Material	Manufacturer	Distributor	Use	Use 2020	Disposal	Recycle	Total Life Cycle (in 2020)
	(kg CO_2-eq.)	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Industrial Fans	101	7	24	19,132	19,132	16	-2	19,277
Electric Motors	315	46	13	22,603	22,603	26	-6	22,998
Electric pumps	57	8	13	45,245	44,273	13	-6	44,357
Distribution and power transformers	9,854	3,064	368	325,874	292,494	4,004	-3,008	306,775
Circulators in buildings	8	1	6	1,738	403	3	-1	420
Residential ventilation	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*

Sources: Ecodesign Preparatory Studies

Annex I. Main parameters and results for Motors and Motor Systems

Table 26. Improved Recyclability Impacts for Motors and Motor Systems

Product	Impact of production +end-of-life per unit	Estimated impact of improved recyclability per unit	Sales in 2020	Estimated impact of improved recyclability for 2020 sales
Units	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(million units)*	*(t CO_2-eq.)*
Industrial Fans	145	4	9,092	27
Electric Motors	395	11	10,850	89
Electric pumps	84	2	1,926	3
Distribution and power transformers	14,281	397	204	81
Circulators in buildings	17	1	9,075	7

Table 27. Extended service life impacts for Motors and Motor Systems

Product	Lifetime	Extension of lifetime	Associated energy consumption of replacement	Benefit/unit	Benefit 2020 sales	Benefit/unit for 1 year additional lifetime	Benefit 2020 sales for 1 year additional lifetime
Units	*(years)*	*(years)*	*(% of initial)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*
Industrial Fans	15	10	100%	89	814	2	22
Electric Motors	12	-	96%	1	0	-81	-879
Electric pumps	11	10	100%	73	140	3	7
Distribution and power transformers	32	-	90%	1	0	-1,267	-259
Circulators in buildings	10	10	98%	8	75	0	4

Table 28. Service economy impacts for motors and motor systems

Product	Efficiency improvement leased products	Low adoption rate	High adoption rate	Factor lifetime low adoption rate	Factor lifetime high adoption rate	Refurbishment % non-use aspects	Impact of better dismantling and recycling BA	Benefit 2020 sales LAR	Benefit 2020 sales HAR	Benefit 2020 sales HAR
Units	*(%)*	*(%)*	*(%)*			*(%)*	*(% of material & EoL)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Industrial Fans	10%	10%	50%	1.0	1.0	10%	0%	1,713	8,566	-132
Electric Motors	10%	10%	50%	1.0	1.0	10%	0%	2,392	11,962	-300
Electric pumps	10%	10%	50%	1.0	1.0	10%	0%	851	4,253	-10
Distribution and power transformers	9%	0%	0%	1.0	1.0	10%	20%	0	0	0
Circulators in buildings	10%	10%	50%	1.0	1.0	10%	20%	35	184	1

Annex J. LCA for Heating and Cooling Products

Table 29. LCA for Heating and Cooling Products - sources: Ecodesign Preparatory Studies

Average impacts per unit:	Material	Manufact-uring	Distribution	Use	Use 2020	Disposal	Recycle	Total Life Cycle (in 2020)
(units)	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*
Chillers								13,027
Tertiary Air Conditioning								426
Central heating products (other than CHP)								74,962
Local room heating products	19	3	8	5,912	4,441	6	-1	4,476
Room air conditioning appliances	152	32	68	5,368	3,237	304	-4	3,789

Note: for central heating and cooling products the estimates were directly calculated at the level of the product group

Annex K. Main parameters and results for Heating and Cooling Products

Table 30. Improved Recyclability Impacts for Heating and Cooling Products

Product	Impact of production +end-of-life per unit	Estimated impact of improved recyclability per unit	Sales in 2020	Estimated impact of improved recyclability for 2020 sales
Units	*(kg CO_2-eq.)*	*(kg CO_2-eq.)*	*(million units)*	*(kg CO_2-eq.)*
Chillers				9
Tertiary Air Conditioning				2
Central heating products (other than CHP)				4
Local room heating products	35	2	26,360	27
Room air conditioning appliances	559	33	9,044	147

Note: for central heating and cooling products, the estimates were directly calculated at the level of the product group.

Table 31. Extended Service Life Impacts for Heating and Cooling Products

Product	Lifetime	Extension of lifetime	Associated energy consumption of replacement	Benefit/ unit	Benefit 2020 sales	Benefit/unit for 1 year additional lifetime	Benefit 2020 sales for 1 year additional lifetime
Units	*(years)*	*(years)*	*(% of initial)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*	*(kg CO_2-eq.)*	*(kt CO_2-eq.)*
Chillers	22	-	79%	1	0	-134	-17
Tertiary Air Conditioning	15	10	74%	28	10	-1	0
Central heating products (other than CHP)	15	-	84%	1	0	-908	-439
Local room heating products	11	-	99%	1	0	-22	-591
Room air conditioning appliances	12	9	91%	147	1,330	1	5

Table 32. Service Economy Impacts for Heating and Cooling Products

Product	Efficiency improvement leased products	Low adoption rate	High adoption rate	Factor lifetime low adoption rate	Factor lifetime high adoption rate	Refurbishment % non-use aspects	Impact of better dismantling and recycling BA	Benefit 2020 sales LAR	Benefit 2020 sales HAR	Benefit 2020 sales HAR
Units	*(%)*	*(%)*	*(%)*			*(%)*	*(% of material and EoL)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Chillers	10%	10%	50%	1.5	1.5	10%	20%	12	72	-2
Tertiary Air Conditioning	10%	10%	50%	1.0	1.0	10%	0%	0	1	-5
Central heating products (other than CHP)	10%	10%	50%	1.0	1.0	10%	0%	403	2,014	-9
Local room heating products	4%	10%	50%	1.5	1.5	10%	20%	514	2,613	115
Room air conditioning appliances	4%	10%	50%	1.5	1.5	10%	20%	218	1,369	601

Annex L. Overview of estimated impacts per type of improvement and per product group

Table 33. Overview of estimated impacts per type of improvement and per product group

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended lifetime	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with no efficiency impact for service economy	Estimated impact Ecodesign and energy labelling
	(kt CO_2-eq.)	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Dishwasher	3	0	227	1,225	123	1,600
Tumble drier	2	0	165	858	71	2,000
Washing machine	15	0	257	1,525	327	2,300
Domestic refrigerators and freezers	12	0	750	3,921	144	4,100
Vacuum cleaners	11	1,762	308	1,766	1,014	8,000
Kitchen appliances	8	0	425	2,277	116	2,000
Non-tertiary coffee machines	2	0	94	502	147	1,000

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended lifetime	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with no efficiency impact for service economy	Estimated impact Ecodesign and energy labelling
	(kt CO_2-eq.)	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Professional wet appliances and dryers	2	0	296	1,504	65	4,000
Professional refrigerating equipment	10	0	340	1,948	634	7,000
Commercial refrigerators and freezers	6	0	275	1,487	382	7,600
Televisions	6,316	23,518	812	5,241	5,740	33,000
Computer Screens	623	1,808	121	719	565	0
Simple set-top boxes	0	0	0	0	0	3,000
Complex set-top boxes	330	1,180	117	686	511	TBC
Video	136	897	28	179	190	0
Game consoles	149	1,495	1	55	209	0
Computer Servers	279	0	476	2,490	437	16,000

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended lifetime	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with no efficiency impact for service economy	Estimated impact Ecodesign and energy labelling
	(kt CO_2-eq.)	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Personal Computers	3,437	20,202	857	4,864	4,571	7,000
Smart Phone	942	4,887	228	1,204	1,263	0
Imaging Equipment	419	4,003	148	588	628	1,000
Industrial Fans	27	814	1,713	8,566	-132	18,200
Electric Motors	89	0	2,392	11,962	-300	57,000
Electric pumps	3	140	851	4,253	-10	1,000
Distribution and power transformers	81	0	0	0	0	5,000
Circulators in buildings	7	75	35	184	1	10,000
Residential ventilation	0	0	0	0	0	0
Chillers	9	0	12	72	-2	0

Impacts for 2020 sales	Estimated impact of improved recyclability	Estimated impact of extended lifetime	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of Low Adoption Rate scenario for service economy	Estimated impacts of High Adoption Rate scenario with no efficiency impact for service economy	Estimated impact Ecodesign and energy labelling
	(kt CO_2-eq.)	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Tertiary Air Conditioning	2	10	0	1	-5	61,000
Central heating products (other than CHP)	4	0	403	2,014	-9	3,700
Local room heating products	27	0	514	2,613	115	8,400
Room air conditioning appliances	147	1,330	218	1,369	601	5,000

Annex M. Analysis of the impact of a 30% increase of CO_2-eq. emissions linked to the production and end-of-life stages

This annex presents the results of an analysis carried out to estimate the impact of a 30% increase in the CO_2-eq. emissions linked to the production and end-of-life stages of products, compared to what is reported in the ErP Preparatory Studies and used in the report. This hypothesis was tested because some sources express concerns that the simplified life-cycle assessment methodology used in the ErP Preparatory Studies may underestimate the CO_2-eq. impact of stages other than use. Overview tables of the impacts from improved recyclability, extended service life and service economy for white goods and related products, consumer electronics, electric motors and motor systems and heating and cooling products are presented below. Lighting is not included in this analysis because a full LCA was used to quantify the CO_2-eq. impacts [US DOE, 2012].

Table 34. Overview of impacts from improved recyclability, extended service life and service economy for white goods and related products

White Goods Products	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended service life 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(baseline years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Dishwasher	3	-201	0	0 (15)	231	1,274	160	1,600
Tumble drier	3	-139	0	0 (13)	168	883	91	2,000
Washing machine	15	-249	0	0 (15)	268	1,651	426	2,300
Domestic refrigerators and freezers	15	-727	0	0 (16)	759	4,019	195	4,100
Vacuum cleaners	13	458	3,042	6 (6)	346	2,023	1,286	8,000
Kitchen appliances	10	-414	0	0 (16)	430	2,347	156	2,000
Non-tertiary coffee machines	2	-39	0	0 (6)	99	537	184	1,000
Professional wet appliances and dryers	2	-314	0	0 (9)	299	1,523	84	4,000
Professional refrigerating equipment	13	-34	0	0 (10)	363	2,136	820	7,000
Commercial refrigerators and freezers	7	-123	0	0 (8)	289	1,591	488	7,600

The following are the consequences of a 30% increase of the CO_2-eq. impact of the production and end-of-life stages for white goods and related products:

- **Improved recyclability**: the effect is very limited; the order of magnitude remains the same.
- **Extended service life**: vacuum cleaners remain the only products for which our estimates indicate that extending the lifetime would lower the CO_2-eq. Emissions.
- **Service economy**: the impact of the scenarios considered for developing the service economy is slightly higher with an increase in the impact of the production and end-of-life stages, but the change is not very significant.

Overall, the effect of an increased impact of the production and end-of-life stages compared to the data used in the report is quite limited for white goods and related products.

Table 35. Overview of impacts from improved recyclability, extended service life and service economy for consumer electronics and related products

Consumer Electronics	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended service life 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(baseline years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Televisions	6,321	2,913	29,722	7 (7)	1,020	6,637	7,288	33,000
Computer monitors	623	227	2,418	7 (7)	141	856	718	
Complex set-top boxes	412	429	1,718	4 (4)	135	808	646	
Video	165	171	1,083	5 (5)	34	219	234	0
Game consoles	189	206	1,752	6 (6)	8	109	267	0
Computer servers	361	-629	0	0 (5)	493	2,607	567	16,000
Personal computers	4,342	5,568	26,042	4.1 (4)	1,056	6,035	5,806	7,000
Smart phone	1,190	2,882	6,175	2.5 (2)	288	1,523	1,599	0
Imaging equipment	526	1,107	5,209	4 (4)	189	753	812	1,000

The following are the consequences of a 30% increase of the CO_2-eq. impact of the production and end-of-life stages for consumer electronics and related products:

- **Improved recyclability**: although there is a visible effect for some products, it remains limited and the order of magnitude remains the same.
- **Extended service life**: the increased impact of products and end-of-life makes a difference in absolute terms as the emissions reduction potential from the first additional year of lifetime increase by about 1Mt CO_2-eq. in the case of TVs, personal computers and smart phones. The order of magnitude however remains the same and these increases do not affect our conclusions on the benefits of extending the service life of these products, nor the selection of products that would represent the priorities in terms of delivering additional CO_2 emissions reduction.
- **Service economy**: like for extended service life, the impact of the scenarios considered for developing the service economy is higher with an increase in the impact of the production and end-of-life stages – up to about 1Mt CO_2-eq. higher for televisions and personal computers – without affecting our conclusions in terms of benefits of the development of a service economy for these product, order of magnitude of the potential prioritisation of products.

Overall, the effect of an increased impact of the production and end-of-life stages compared to the data used in the report can have a quite significant effect on the absolute value of potential emissions reduction. Those changes however don't affect our conclusions in terms of the overall order of magnitude of the potential emissions reduction to be delivered by the various improvement considered, or of the potential prioritisation of products or types of improvements to be stimulated.

Table 36. Overview of impacts from improved recyclability, extended service life and service economy for motors and motor systems

Motors and Motor Systems	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended service life - 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(baseline years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Industrial Fans	34	28	1,018	10 (15)	1,706	8,532	-165	18,200
Electric Motors	115	-838	0	0 (12)	2,375	11,875	-387	57,000
Electric pumps	4	8	175	10 (11)	850	4,250	-12	1,000
Distribution and power transformers	105	-275	0	0 (32)	0	0	0	5,000
Circulator pumps in buildings	8	6	103	10 (10)	35	185	2	10,000

The following are the consequences of a 30% increase of the CO_2-eq. impact of the production and end-of-life stages for motors and motor systems:

- **Improved recyclability**: the effect is very limited, with a maximum difference of 25kt CO_2-eq. for electric motors and distribution and power transformers; the order of magnitude remains the same.
- **Extended service life**: the effect on a one-year extension of the lifetime is very limited. For a longer extension, the largest difference is for electric motors and reaches 0.2 Mt CO_2-eq. General conclusions on the benefits of extending the lifetime of the various products considered here are not affected by an increased impact of the production and end-of-life stages.
- **Service economy**: The scenarios considered for a development of a service economy for these products do not include an extension of the lifetime. The effect of a 30% increase of the CO_2-eq. impact of the production and end-of-life stages on these scenarios is therefore practically nil.

Overall, the effect of an increased impact of the production and end-of-life stages compared to the data used in the report is limited for motors and motor systems. The most noticeable impact is that a significant (5 years) extension of the lifetime for electric motors would avoid an extra 0.2 Mt CO_2-eq. emissions. This variation of the value of the impact is relatively important in regards of the modelled impact of an extended service life for this product category, but still very minor compared to the impact of for example the Ecodesign Regulation for electric motors (about 57 Mt CO_2-eq.).

Table 37. Overview of impacts from improved recyclability, extended service life and service economy for heating and cooling products

Heating and Cooling products	Estimated potential benefit improved recyclability for 2020 sales	Estimated potential benefit Extended service life - 2020 sales			Estimated potential benefit Service Economy - LA - 2020 sales	Estimated potential benefit Service Economy - BA - 2020 sales	Service Economy Average efficiency - Improved Refurbishment - IR-BA - 2020 sales	Estimated benefits of Ecodesign and Labelling regulations
		1 year extension	Optimal extension	# extra years (baseline years)				
Units	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(years)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*	*(kt CO_2-eq.)*
Chillers	11	-18	0	0 (21)	12	75	-2	0 61,000
Tertiary Air Conditioning	3	0	19	10 (15)	0	-1	-6	
Central heating products (other than CHP)	5	-438	0	0 (15)	402	2,011	-11	3,700
Local room heating products	33	-581	0	0 (10)	518	2,645	146	8,400
Room air conditioning appliances	186	49	2,277	10 (13)	240	1,559	774	5,000

The following are the consequences of a 30% increase of the CO_2-eq. impact of the production and end-of-life stages for heating and cooling products:

- **Improved recyclability**: the effect is very limited; the order of magnitude remains the same.
- **Extended service life**: the only noticeable impact is for RAC. Our estimate of the impact of extending the lifetime of RAC units is almost 1 Mt CO_2-eq. higher. The optimal lifetime extension goes from9 years to 10 years. For other products the effect is negligible.
- **Service economy**: the impact of the scenarios considered for developing the service economy is slightly higher with an increase in the impact of the production and end-of-life stages, but the change is not very significant. As for the extended service life, the largest difference, both in relative and absolute terms, is for RAC units. For BA and IR-BA scenarios the difference is reaches nearly 0.2 Mt CO_2-eq. This is relatively important compared to the total estimated potential for developing service economy practices for RAC, but does not affect our conclusions concerning the potential benefits of service economy for these products or heating and cooling products in general.

Overall, the effect of an increased impact of the production and end-of-life stages compared to the data used in the report is quite limited for heating and cooling products. The most noticeable impact is that the estimated potential emissions reduction from an extension of the lifetime of RAC units is almost 1 Mt CO_2-eq. higher if the input data assumes a 30% higher impact for production and end-of-life stages than what is reported in the ErP Preparatory Studies. Those changes however don't affect our conclusions in terms of the overall order of magnitude of the potential emissions reduction to be delivered by the various improvement considered, or of the potential prioritisation of products or types of improvements to be stimulated.