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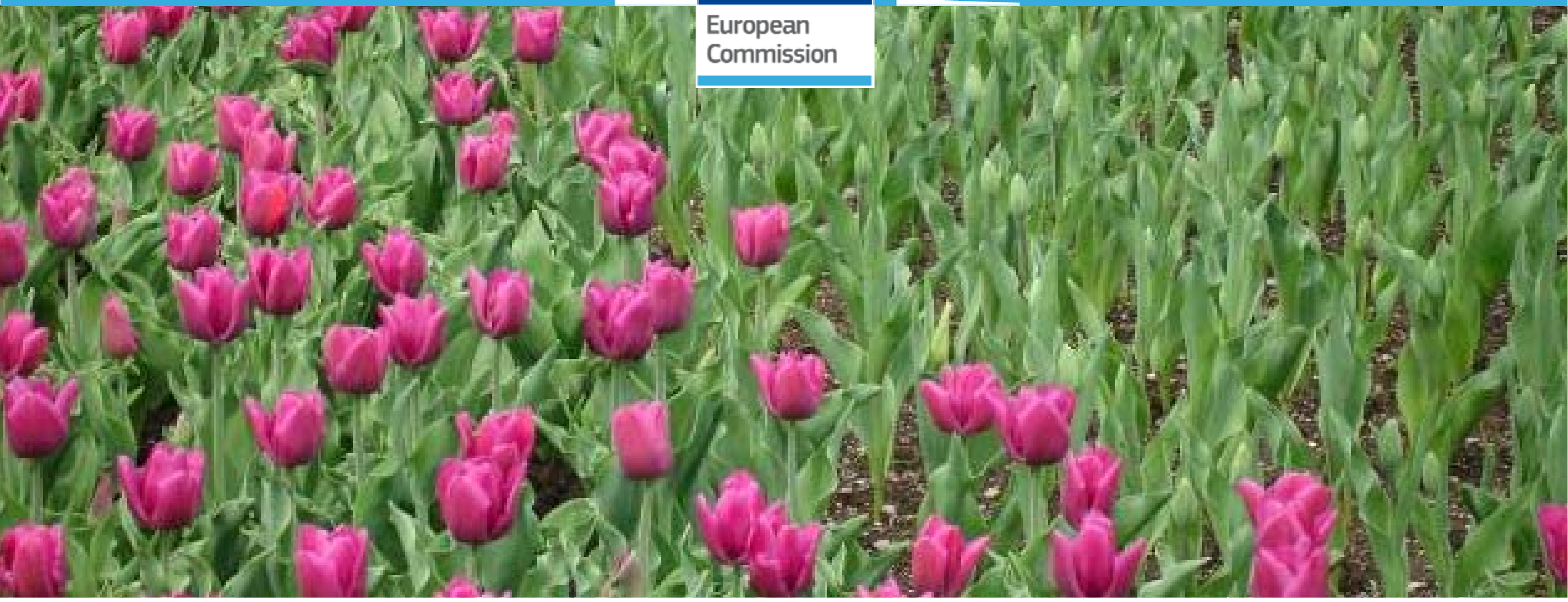

J R C T E C H N I C A L R E P O R T S

Integration of resource efficiency and waste management criteria in European product policies – Second phase

Report n° 2
Application of the project's methods to three product groups (final)

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Executive Summary

The objectives of the present Report n° 2 are:

- the application and testing of developed methods for the assessment of resource efficiency parameters (reusability/recyclability/recoverability-RRR, use of relevant resources, recycled content, use of hazardous substances, durability) on some representative and relevant case studies;
- the analysis of the methods for the identification and assessment of ecodesign requirements potentially relevant at the case-study product level and at the product group level.

Identification of relevant case studies

The first part of the report (Chapter 1) focuses on the 'high level assessment' of flows of materials in the EU-27 and the estimation of their environmental impacts. The analysis aims at identifying relevant materials (and the product groups that embed them) which contribute significantly to life-cycle impact categories at the European level.

The analysis is fed by a review of studies in the scientific literature concerning impacts associated with certain materials and products. Amongst approximately 60 materials considered (including various common polymers) the most relevant materials are identified, for the purpose of the study, in terms of specific impacts per unit of mass and of overall impacts in the EU-27.

The report subsequently analyses some product groups in order to identify some case-studies potentially relevant for the scope of the study (Chapter 2). Thirty-six product groups (mainly Energy Related Products-ErP, but including also some 'Non-ErP') have been considered and assessed against 8 criteria. The outcome of the analysis is the selection of three case-studies that cover some of the parameters, based on relevance and data availability:

- the 'imaging equipment' product group (limited to the analysis of the recycled content)
- the 'washing machine' product group (for the analysis of RRR, use of relevant resources, use of hazardous substances and durability)
- the 'Liquid Cristal Display (LCD) TV' product group (for the analysis of RRR, use of relevant resources and use of hazardous substances).

Definition of typologies of product requirements suitable for the 3 case studies

An analysis of potential product requirements concerning resource efficiency and waste management parameters (Chapter 3) was conducted based on a survey of ecodesign criteria developed in environmental labelling schemes and scientific literature. Based on expert judgement, a typology of 20 possible criteria was proposed, consisting of declarations, threshold criteria, provision of information and implementation of design alternatives for ecodesign.

Definition of a method for the identification of potentially relevant product requirements

A method for the identification and assessment of potentially relevant product requirements is also introduced and discussed (Chapter 4). This method combines the application of the project methods

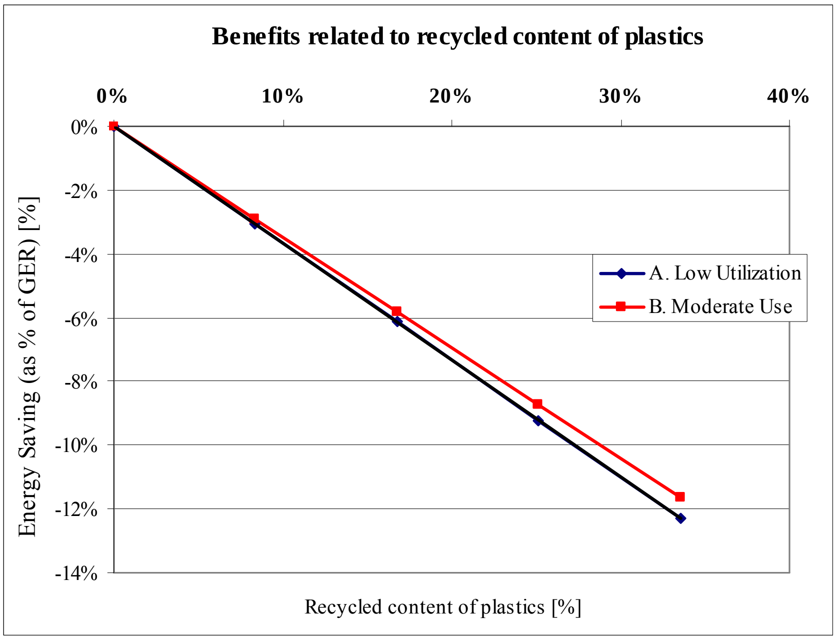
(Report n° 3) to a product group first to identify 'hot spots' (key components and/or product parameters that are relevant in terms of relevant life-cycle impacts and/or improvement potential) and then to assess, within the typology of requirements previously defined, those that could produce relevant environmental benefits (both at the case-study product level and at the product group level).

Analysis of case-studies

The last part of the present Report focuses on the three case-studies previously selected. It is demonstrated that it is possible to assess the performance of the product according to resource efficiency parameters using available data (or easily available data). It is also shown that the method results in the identification of potentially relevant products requirements. Details on each case-study follow:

- Analysis of the "Imaging Equipment" (Chapter 5 - analysis limited to recycled content): it is based on data and information from the Energy using Product (EuP) preparatory studies for Ecodesign implementing measures for the product category. The Ink Jet- multi functional device is identified as a potentially relevant and representative case-study product. Different scenarios are analysed, based on: different assumptions concerning the percentages of recycled plastic for the manufacturing of the product; different scenarios considered for the energy consumption during the use phase; different ecoprofile of recycled plastics considered. The analysis is performed using data extracted from the 'Methodology for the Ecodesign of Energy-related Products - MEErP ecoreport tool'. It is observed that significant (from 3% to 10%) reductions of life-cycle energy consumption could potentially be achieved by setting a requirement concerning the use of variable percentages (from 10% to 30%) of recycled plastics during the manufacturing. For example, Figure A illustrates some variations of the 'Global Energy Requirement' impact with different percentages of recycled content of plastics. Such results can be used to identify potentially relevant requirements on recycled content of plastics for the imaging equipment product group.

Figure A. Variation of the Global Energy Requirement (GER) with different percentages of recycled content of plastics in the case-study of imaging equipment



- Analysis of the "Washing machine" (Chapter 6 - for the analysis of RRR, use of relevant resources, use of hazardous substances[1]) is based on data and information from manufacturers on two case-study products, complemented by information from recyclers[2] and the scientific literature. Current End-of-Life treatments for washing machines are analysed to identify representative End-of-Life scenarios for the EU context. The analysis firstly focuses on the application of the project methods, showing a high variability in results for the two considered products. Some identified 'hot spots' of the washing machine are: counterweights (which largely influence the mass indices of the product), Printed circuit Boards and electronics (which are relevant for some impact categories and for the content of some EU critical raw materials), and the motors (which are relevant for the environmental impacts of copper and of some rare earths, potentially embedded in high efficiency motors). The analysis identifies and assesses some potential ecodesign requirements. Among these, disassemblability requirements (on the Printed circuit Boards, motors and LCD-screen, if any) are identified as potentially being the most relevant due to the contribution to the improvement of the performances of the product during End-of-Life treatments, thanks to the increase of the recycling rates of some relevant materials (copper and precious metals). For example, Table A illustrates some estimated variation of recycled metals due to the application of the requirement on the disassemblability of the printed circuit boards. Some additional requirements concerning the provision of information (about relevant materials in the washing machine) and declarative and thresholds requirements of some recyclability indices are also analysed.

[1] The analysis of durability for the WM case-study will be illustrated in Report n° 1.
[2] The study has been mostly based on data from pre-treatment facilities. However some data from final recyclers have been collected directly or indirectly (thanks to information on the final treatments of materials from pre-treatment facilities or association of recyclers). Missing information has been complemented by references from the scientific literature.

Table A. Benefits in terms of additional recycled masses for the washing machine case-study due to the application of the requirement on the disassemblability of the printed circuit boards

	copper	silver	gold	palladium	platinum
A. Overall quantities of metals yearly used in the EU27 [10^3 kg/year]	3,525,910	12050	130	720	
B. Overall quantities of metals yearly used in the washing machines [10^3 kg/year]	2,735	10.39	1.76	0.52	0.11
C. Overall benefit (additional recycled mass) [10^3 kg/year]	478.67	4.18	0.63	0.19	0.039
Mass fraction (C/A) [%]	0.01%	0.03%	0.48%	0.03%	
Mass fraction (C/B) [%]	17.5%	40.3%	35.7%	36.7%	

- Analysis of the "LCD-TV" (Chapter 7 - for the analysis of RRR, use of relevant resources and use of hazardous substances) is based on data and information from one product case-study from a recycling company and complemented by information from the scientific literature. Current End-of-Life treatments of LCD-TVs are generally based on a full manual dismantling of the product; on the basis of this information a representative 'dismantling' End-of-Life scenario has been defined for the EU context. The analysis firstly focuses on the application of the project methods, showing generally high values of the calculated indices (e.g. recoverability, recyclability) with the current (manual dismantling based) scenario. This is due to the high efficiency of current End-of-Life treatments that allow high recycling rates of all the material fraction and consequent high environmental benefits. In particular, the dismantling based scenario allows to optimize the recycling of relevant materials from Printed circuit Boards, and it allows materials otherwise not separable by mechanical treatments (for example the polymethyl methacrylate – PMMA - board) to be recycled. The chapter also analyses the dynamic evolution of the End-of-Life scenario, mainly due to a growing percentage of the shredding-based End-of-Life scenario. If confirmed in future, this trend would imply lower recycling rates for various materials. Some potential product requirements are discussed with the aim of supporting the improvement of the current End-of-Life scenario and to make it more competitive in the future. These requirements include: the improved disassemblability of key parts (fluorescent lamps, Printed circuit Boards, LCD screen and polymethyl methacrylate board). For example Table B illustrates the benefits due to the application of the requirements, in the different situations of evolution of the End-of-Life scenario. Furthermore, the disassemblability of such parts allow the preparation of waste for further recycling processes, currently under research and/development, as the recycling of rare earths from lamps and of indium from LCD screens. Further potential requirements for LCD-TVs, such as the threshold for the 'recyclability rate' of plastic parts and the declaration of content of indium in the product are illustrated.

Table B. Benefits in terms of additional recycled masses for the LCD-TV case-study due to the application of the requirement on the disassemblability of key components in different scenarios (situations B[3] and C[4])

Material	X. Benefits in term of additional recycled mass		Y. Overall amount of materials used in the LCD-TVs [10^3 kg/year]	Z. Overall amount of materials used in the EU [10^3 kg/year]	Fraction of the additional recycled material compared to the uses in LCD-TVs (X / Y) [%]		Fraction of the additional recycled material compared to the overall uses in the EU (X / Z) [%]	
	Situation B [10^3 kg]	Situation C [10^3 kg]			Situation B [%]	Situation C [%]	Situation B [%]	Situation C [%]
Steel	128	256	73,143	79,926,821	0.2%	0.3%	0.00016%	0.00032%
Aluminium	104.7	209.4	13,090	5,020,336	0.8%	1.6%	0.002%	0.004%
PMMA	10,055	20,111	53,487	180,002	18.8%	37.6%	5.6%	11.2%
ABS	2,064.3	4,128.5	51,607	752,039	4.0%	8.0%	0.27%	0.55%
Copper	357	714	5,701	3,525,913	6.3%	12.5%	0.01%	0.02%
Silver	2.94	5.89	18.3	12,050	16.1%	32.2%	0.024%	0.049%
Gold	1.0	2.0	7.0	130	14.3%	28.6%	0.77%	1.53%
Palladium	0.214	0.429	1.5	720	14.7%	29.4%	0.03%	0.06%
Platinum	0.012	0.024						

The analysis of case studies shows that the methods are applicable to the products under scope with available data and it is possible to analyse the performance of products on the basis of the various indices including: RRR rate (including RRR for plastics and/or CRMs) RRR Benefit rates, Recycled content, Recycled content Benefits, presence of hazardous substances in components. It is also shown that the methods can be used to transparently identify potentially relevant product requirements, and to assess their potential benefits. Requirements should be assessed considering the whole life cycle of the product, including use phase and any other relevant phase, in order to minimize trade-off and optimize global environmental benefits.

The outcomes of the application of the methods to case studies have also been used to revise the methods as presented in Report n° 3.

[3] Thanks to application of requirements on the disassemblability of some TV parts, an additional share of 20% of the overall LCD-TV is assumed to be dismantled in the future instead of being shredded and mechanically sorted

[4] Thanks to application of the requirements on the disassemblability of some TV's parts, an additional share of 40% of the overall LCD-TV is assumed to be dismantled in the future instead of being shredded and mechanically sorted

Abbreviations

ABS - Acrylonitrile Butadiene Styrene
CCFL – Cold Cathode Fluorescent Lamp
CRM – Critical Raw Materials
EEE – Electrical and Electronic Equipment
EP1 – "Ecodesign Phase 1" project[5]
EPS- Expanded polystyrene
ErP – Energy Related Product
EuP – Energy Using Product
GER – Global Energy Requirement
GWP – Global Warming Potential
HI-PS – High Impact Polystyrene
IJ-MFD – Ink Jet Multi Function Device
LCA – Life Cycle Assessment
LCD – Liquid Crystal Display
MEErP - Methodology for the Ecodesign of Energy-related Products
PA - Polyamides
PC – Polycarbonate
PCB – Printed Circuit Board
PE-HD – Polyethylene high density
PE-LD – Polyethylene low density
PET – Polyethylene terephthalate
PGMs – Platinum Group Metals
PMG - Platinum Group Metals
PMMA - Polymethyl methacrylate
PP - Polypropylene
PS - Polystyrene
PUR - polyurethane
WEEE – Waste of Electrical and Electronic Equipment
WM – Washing Machine

[5] Project between JRC/IES and DG Environment titled: "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive". Reports of EP1 available at: http://lct.jrc.ec.europa.eu/assessment/projects

Introduction

The present document is the second report of the project "Integration of resource efficiency and waste management criteria in European product policies – Second phase"[6].

The objective of the project is to support the European Commission for the integration in European product policies (including the Ecodesign policy) of measures aiming at improving resource efficiency and end-of-life of the products[7]. In particular, the current project aims at developing a series of concise documents for use as reference methods for measuring/assessing and verifying the performances of products according to the following parameters:

- recyclability/recoverability/reusability (RRR),
- recycled content,
- use of priority resources,
- use of hazardous substances,
- durability.

The scope of the present report is the test of the project's methods on at least two case studies and the identification and assessment of potential related ecodesign requirements and their verification for European policies. The report will be subdivided in four parts:

- High level environmental assessment (Chapter 1). This section identifies products categories and materials that are responsible, at the European level, of the largest environmental impacts other than climate change impacts and energy consumption during the use phase.
- Identification of case-studies (Chapter 2) potentially relevant for the objective of the project.
- Review of product policy measures into scientific and technical literature (Chapter 3). It performs a review of potential ecodesign measures applicable to products. This task will summarize the availability of criteria and requirements adopted by technical schemes (e.g. Ecolabel and other product's labelling schemes) or discussed in the scientific literature.
- Definition of a procedure (Chapter 4) for the identification of potentially relevant ecodesign requirements for a selected case-study product.
- Analysis of the selected case-studies (Chapter 5, 6 and 7). These sections apply the developed methods to the imaging equipment, washing machine and Liquid Crystal Display - LCD-TV product groups. For each case-study, potentially relevant ecodesign requirements are also identified and related environmental benefits are assessed.

[6] Administrative Arrangement between DG Environment and the DG JRC-IES n◦ 070307/2009/546207/G2.

[7] This project follows the previous "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive"

1. High level environmental assessment

1.1 Introduction

The following sections aim at identifying the materials and product categories responsible, at the European level, of the largest environmental impacts, following a multi-criteria approach.

A similar approach is being currently developed by JRC-IES in the so-called Life-Cycle based monitoring Indicators (see http://lct.jrc.ec.europa.eu/assessment/projects). Since the final report of the Indicators project was not available at the start of the current project, a less ambitious approach has been developed, still ensuring consistency with the Indicators project. In the future, the present "High level environmental assessment" will have to be revised to be in line with the recommendations of the Indicators project.

The analysis will be based on available data in the current scientific literature, giving preliminary answers to the following questions:

- what percentage of the total metals/plastic/other specific priority resources extracted/imported in EU is included in products used in EU?
- what is the proportion of environmental impacts (other than energy in use) generated by products?
- Are these mass flows and environmental impacts relevant?

The analysis first performs a review of already published studies on the above mentioned topics.

Afterwards the method for the environmental analysis of materials and products is introduced.

Finally most relevant materials and product groups are identified and discussed.

1.2 Literature review on the environmental impacts of products

The scientific literature presented various studies concerning the environmental impacts of materials and products. The following sections illustrate the main outcomes of some of those studies. These outcomes will be used as basis for the comparison of the results from the project's 'high level impact assessment' task.

1.2.1 Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25

One of the possible actions on the sustainable use and management of natural resources is the "*breaking the linkage between economic growth and resource use*" *reducing or avoiding* *environmental impacts*” [van der Voet et al., 2005]. However, how this decoupling should be accounted for is not well defined.

The study “*Policy Review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries*” [van der Voet et al., 2005] has been financed by the European Commission with the scope to define and apply methods on how to monitor the progress on the decoupling road.

As underlined in the study “*it is the environmental pressures and impacts respectively which should be decoupled from economic growth, not their use per se*”. In particular the authors develop an indicator combining information on material flows with information on environmental impacts. This indicator has been called EMC (Environmentally weighted Material Consumption). The idea behind the environmentally weighed material consumption indicator, EMC, is simple:

“*to multiply the material flows with a factor representing their environmental impact. […] To specify the environmental impacts of a material, a Life Cycle Impacts approach is taken*” [van der Voet et al., 2005]. The method steps are:

- The use of life-cycle data per kg of material;
- The multiplication of the impacts by the number of kilograms of this material being consumed within the considered economy;
- The aggregation (by weighting) of the impacts and comparison to overall reference values.

The scope is to “*obtain an idea of the environmental impact of the consumption of the material. Summated over all materials, a picture emerges of the potential environmental impact of the material consumption of a national economy*”. Figure 1 illustrates the normalized and aggregated impacts of some materials in the EU in the period 1992-2000.

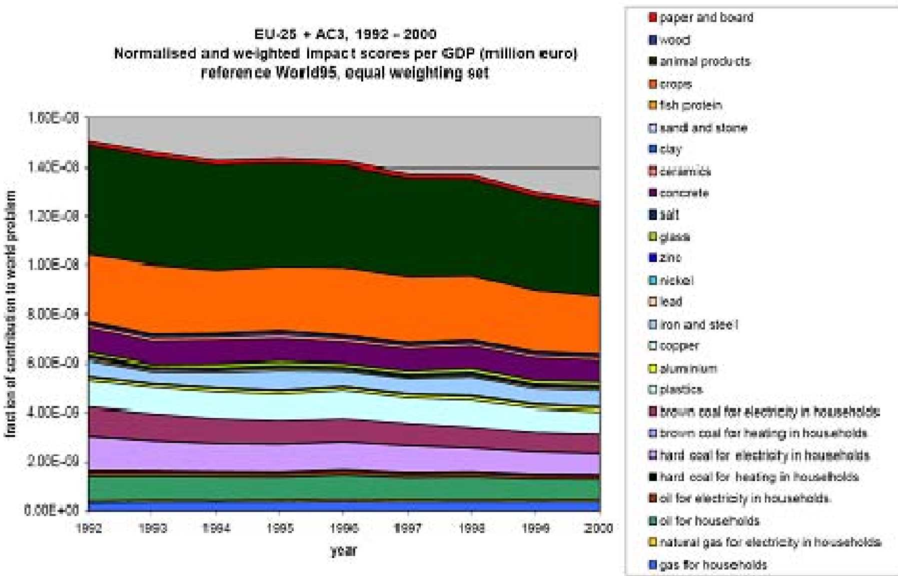


Figure 1. Impacts of materials in the EU25 [van der Voet et al., 2005]

It is possible to observe that:

- the largest amount of used materials is related to construction materials (concrete, sand and stone). However, their impacts are lower compared to other product categories (due to their very low specific impacts).
- the largest impacts are related to food production (animal products and crops)
- large impacts are also related to the use of fossil fuels.
- Relevant impacts are also related to iron and steel and plastics. The contribution of other metals (e.g. aluminium, zinc, nickel and lead) is instead much lower (although they are characterized by high environmental specific impacts).

The study also underlines some potential limits of the results, as [van der Voet et al., 2005]:

- Potential Double-counting: because the impact factor relates to cradle-to-grave chains. Therefore, life-cycle impacts of some materials (e.g. copper) also include impacts of other materials (e.g. iron used for the copper extraction and treatments. The authors tried to face this problem "*by excluding materials that are used solely for the production of other materials*". However, this avoids the double accounting only partially.
- Resources vs. finished materials: the indicators are built up out of raw materials, finished materials and products. Cradle-to-grave impact factors refer to finished materials.
- Included and excluded materials: The idea is to include as many materials as possible. Two restrictions have been considered: (1) information on the materials consumption should be available, and (2) information on the environmental impact of the material should be available.
- Weighting: authors used the ETH-database for the Life Cycle Inventory (LCI). The LCI was aimed at specifying all environmental interventions in terms of extractions and emissions of 1 kg of each material. The results of the LCI were translated with LCA software (the CMLCA program) into contributions to 13 different impact categories. Afterwards the authors underline that their aim is to arrive at one single indicator for environmental impact: these 13 indicators have been therefore aggregated. Aggregation cause, however, additional uncertainty to the results.

1.2.2 Environmental impacts related to the final consumptions of the EU25

In 2006 the European Commission – Joint Research Centre – IPTS – published the study "Environmental Impact of Products (EIPRO)" [JRC, 2006]. The study identified those products that have the greatest environmental impact throughout their life-cycle, from cradle to grave based on an input-output model.

The scopes of the project were:

- To focus on identifying products on the basis of their life-cycle impacts. Identify products on the basis of the overall volume of the product used.
- To focus primarily on the life-cycle impacts of products (both goods and services) in terms of final consumption in the 25 Member States of the EU (both household and government expenditure). Include all processes related to resources extraction, production, use and waste

management (both inside and outside the EU-25), so as to account for total final consumption in the EU-25.

- To describe the current situation taking a reference year around 2000. The study did not include analyses of developments over time and in the future.
- To include capital goods, and where possible, pay attention to specific materials such as packaging and other intermediate products.
- To use, where relevant, a variety of impact assessment methods.

The study also performed a review of the scientific publication to assess the potential agreement/disagreement on product category with the largest environmental impacts (Table 1). From the review, the following groupings came up as relevant product groups [JRC, 2006]:

- packaging (household and industrial)
- office appliances (copiers, computers and peripherals, etc.)
- non-residential building occupancy (heating, lighting in office buildings, etc.)
- non-residential construction (i.e. office buildings, civil work)

Afterwards the study identified the following three areas as having the greatest impact:

- food and drink
- private transport
- housing

There is no clear ranking, as products in the three areas identified are of approximately equal importance. Together they are responsible for 70 – 80 % of the environmental impact of consumption, and account for some 60 % of consumption expenditure.

More detailed conclusions can be given for the main functional areas of consumption:

- Food and drink cause 20 – 30 % of the various environmental impacts of private consumption, and this increases to more than 50 % for Eutrophication. This includes the full food production and distribution chain 'from farm to fork'. Within this consumption area, meat and meat products are the most important, followed by dairy products.
- The contribution of passenger transport to the total environmental impacts of private consumption ranges from 15 to 35 %, depending on the category. Based on the data used for the study, the greatest impact is from cars, despite major improvements in the environmental performance in recent years, especially on air emissions.
- The products under the heading of housing include buildings, furniture, domestic appliances, and energy for purposes such as room and water heating. Together they make up 20 to 35% of the impacts of all products for most impact categories. Energy use is the single most important factor, mainly for room and water heating, followed by structural work (new construction, maintenance, repair, and demolition). The next important products are energy-using domestic appliances, e.g. *refrigerators* and *washing machines*.

- All other areas of private consumption together (i.e. excluding food and drink, transport and housing) account for no more than 20 – 30 % of most environmental impacts. There are uncertainties about the percentage contributions of the remaining products, but most of the evidence suggests that clothing ranks highest, accounting for between 2 and 10% of total environmental impact.

Table 1 Main product groupings and environmental impacts (modified from [JRC, 2006])

Product category	Energy	Land use	Resource Depletion	Water consumption	Eutrophication	Greenhouse gas	Phot. Smog	Acid.	Waste
Food and beverages	++	++	++ (energy related, biomass) ++ (non- energy related)	++	++	+(-)	+	++	+(+)
Clothing and footwear		+(-)	++ (energy and non-energy, mineral, biomass, synthetic) + (metal)	+	+(-)	+(-)	+(-)	+	+(-)
Construction – Residential dwellings	+(-)	++				+	+	+(-)	++
Water supply and misc.services related to dwellings				+(+) (toilet and sanitary use)					
Electricity, gas and other fuels									
Heating / Hot water	++		+(+) (energy related)			++	+(-)	+(+)	
Lighting	+(-) (important domestic and commercial)		+(-) (energy and non-energy)						
Furniture			+(-) (non- energy related, metals)		+(-)				+(-)
Household appliances	+(-)		+(-)			+(-)	+(-)	+(+)	
Food storage, preparation, dishwashing			+(-)				+(-)		
Maintenance clothes and textiles	+(-)		+(-) (energy and non-energy)						
House maintenance									
Audio, TV, computer, etc.			+(-) (non-energy)						
Office appliances (incl. paper use)	+(-) (energy use in offices, public administration etc…)		+(-) (organic, depends on product definition)						+(+) (paper products)
Personal vehicles	++		++ (energy and non-energy, metal, synthetic)			++	++	++	+(-)
Restaurants and hotels		+(-)		+(-)	+(-) ('holidays' and 'restaurant, pub')		+(-) ('holidays')	+(-) ('holidays' and 'restaurant, pub')	
Household packaging			+(-) (synthetic) - (depletion)					+(-)	++

++ : agreement on high relevance
+ : agreement on relevance, but not with the highest contributors

1.2.3 UNEP's studies on the environmental impacts of products

Various studies have been carried out by UNEP on the theme of resource efficiency and impacts of the products. Some of these studies will be briefly presented in the next sections.

1.2.3.1 Priority Products and Materials

An interesting review about the impacts of products and materials has been carried by UNEP in 2010, with the scope of "*to provide insight into the economic activities that cause the highest environmental pressures*" [UNEP, 2010].

The first part of the study focused on relevant environmental impacts. It is recognised that "*the most critical pressures and impacts caused by economic activities are related to ecosystem health, human health and resource depletion. Of these, human health and environmental health impacts are best researched. Habitat change is the most important cause for ecosystem degradation, while air pollution and climate change impact human health*" [UNEP, 2010].

In particular, the authors suggest the analysis of the following impact categories for study focusing on the impacts of materials and products:

- Impacts caused by emissions:•
    - o Climate change (caused by Greenhouse gas (GHG) emissions)

- Eutrophication (over-fertilization caused by pollution with nitrogen and phosphorus)
- Human and ecotoxicity effects (caused by urban and regional air pollution, indoor air pollution and other toxic emissions).

- Impacts related to resource use:
    - Depletion of abiotic resources (fossil energy carriers and metals)
    - Depletion of biotic resources (most notably fish and wood)
    - Habitat change and resource competition due to water and land use.

Concerning the 'resource depletion', the study underlines that "*authoritative global assessments in the area of resource depletion are lacking. The academic literature disagrees on whether resource scarcity, or competition for scarce resources, presents a fundamental problem or is easily solved by the market. Demand projections indicate, however, that the consumption of some metals and oil and gas will outstrip supply and may exhaust available reserves within the current century. A specific but not yet fully researched problem may be 'linkages' between issues such as declining ore grades, resulting in higher energy needs for mining and refining, whereas these same depleting resources are needed in much higher amount in future for sustainable energy production and storage systems (e.g. PV cells and batteries)*". For biotic resources, the overexploitation has already led to the collapse of resource stocks especially in the case of fisheries. In addition, competition over land and availability of fresh water is a serious concern.

Figure 2 illustrates the contribution of some economic sectors to some impacts categories (figures relate to the USA context). It is possible to observe that the energy supply, electricity production and transport are the main contributors to GWP, acidification. Various different crops are the main responsible of the freshwater ecotoxicity. Human toxicity category is instead largely influenced by industrial process including the production of paper, chemical, copper, non-metallic minerals and photographic equipment.

Figure 3 illustrates the Relative contribution the impact of resource scarcity (concerning the categories of 'fossil fuels' and 'metals') for the world in 2000 by resource category. The study assess that "the depletion of crude oil and natural gas is more serious than that of coal. For the metals, the depletion of platinum, gold and rhodium are evaluated to cause almost all the scarcity. When the two are combined, fossil fuel scarcity is evaluated to be much more serious than metal scarcity".

The UNEP study also addressed the analysis of the impacts of materials. Authors underlined that two main approaches can be used to prioritize materials [UNEP, 2010]:

- Material Flow Analysis only counts the mass of materials used.
- Impact based indicators (analogous to the 'EMC indicator' illustrated in section 1.2.1) that include additionally a weighting factor reflecting the life-cycle impacts per kg of material.

Some conclusions of the study are [UNEP, 2010]:

- Concerning metals, although many of them have high impacts per kg compared to other materials, in view of the comparative size of their flows, only iron, steel and aluminium enter the priority lists. A priority list of metals based on their environmental impacts is presented in Table 2 (including the ranking by specific impacts and by global impacts);

- Fossil fuels and materials are relevant. Fossil fuel combustion is the most important source of most emissions-related impact categories. Plastics are important in terms of impacts among materials.

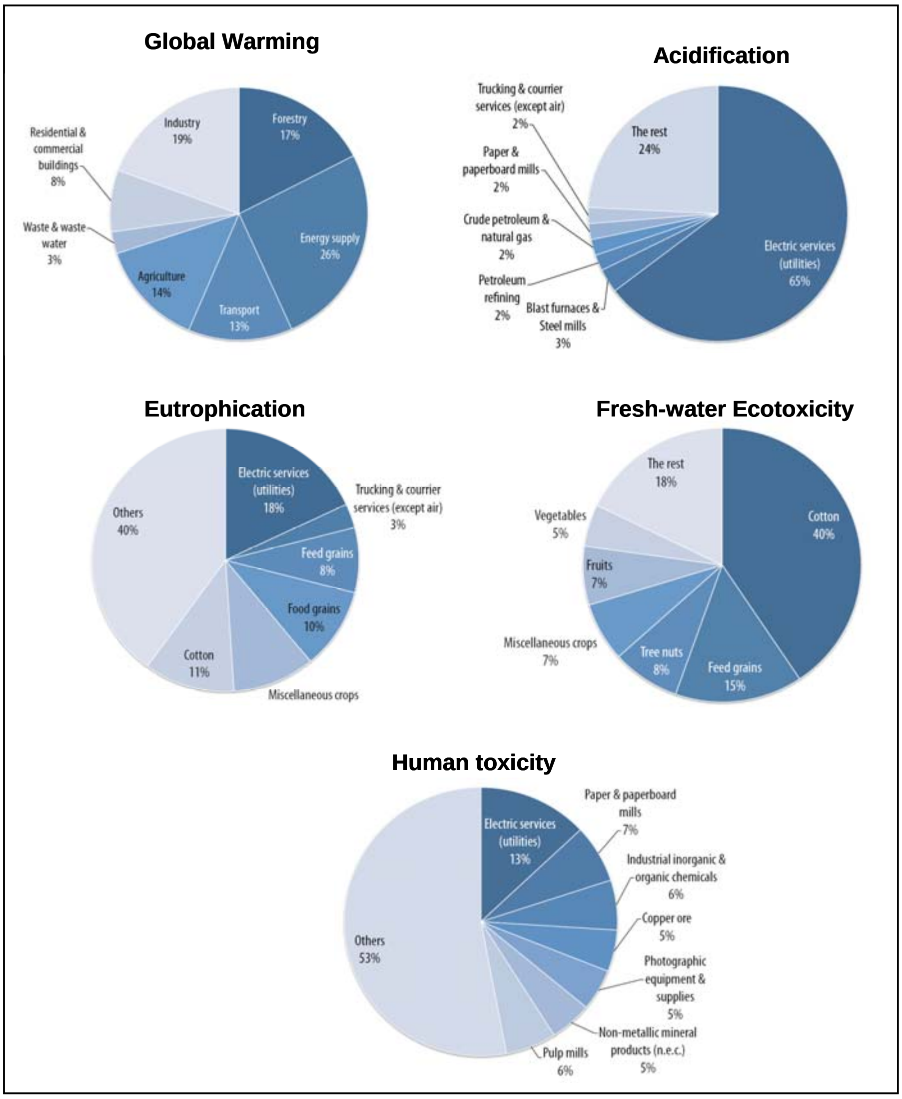


Figure 2. Contribution of some economic sectors to impact categories (in the USA)[UNEP, 2010]

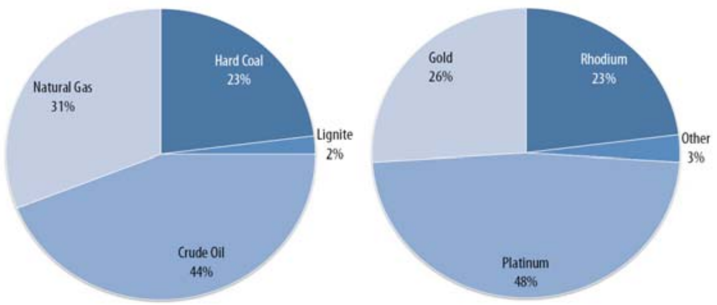


Figure 3. Relative contribution to the impact category of 'resource scarcity' for the world in 2000 by resource category (fossil fuel and metals categories). [UNEP, 2010][8]

[8] The figures suggest that for fossil energy carriers oil and gas are most scarce, and for metals platinum, gold and rhodium are most scarce.

Table 2 Priority list of metals based on their environmental impacts [UNEP, 2010].

	Impact global production primary metals	Impact per kg primary metals
1	Iron	Palladium
2	Chromium	Rhodium
3	Aluminium	Platinum
4	Nickel	Gold
5	Copper	Mercury
6	Palladium	Uranium
7	Gold	Silver
8	Zinc	Indium
9	Uranium	Gallium
10	Silicon	Nickel

1.2.3.2 Sustainable use of metals

Resource depletion is one of the themes discussed by UNEP reports. In Particular, the Global Metal Flows Group of the UNEP is currently developing various studies about the consumption and the impacts of metals in our economy [UNEP 2010b]. "*Metal minerals constitute the largest set of mineral resources with more than sixty different elements in all*". "*Modern technology is totally dependent on perhaps four of them the iron and manganese that form structural steels, the aluminium widely used in transportation, the lead used for storage batteries, and the copper that transmits power from the generator to the user*".

Other largely relevant metals are: chromium and nickel that (together with iron) form stainless steels, zinc that inhibits metal corrosion, and tin that is essential to modern electronics.

A key question that UNEP aims to answer is whether the society needs to be concerned about long-term supplies of any or many of them. In particular, the UNEP planned a series of six reports[9], aiming at answering questions as the followings [UNEP, 2010b]:

- "*To what extent is information available on the metal stocks in society? […]*
- *What is the efficiency with regard to metal recovery?*
- *What are the recycling rates of metals in various countries, various regions, and the planet as a whole?*
- *What are the related environmental impacts of different metal mining refining and recycling techniques? […]*
- *To what extent can end of life discard streams from electronics, automobiles, and other products be used as a secondary source of metals?*
- *What information is needed to develop realistic scenarios for potential metal stocks and rates of use in the future? […]*
- *For which metals may supplies become critical and over what time frames?*

[9]Currently the first two reports have been published, while the others are under development.

- *Is today's use of metals sustainable? If not, what policy options are suggested?*"

One aspect of the availability of metals concerns the natural (or virgin) stocks of metals: those deposited by geological processes in concentrations suitable for being extracted and processed, now and in the future. The total amounts of metals in such deposits are difficult to quantify accurately, but global estimates are publicly reported (e. g., USGS or BGS[10]). Other interesting stocks are 'anthropogenic' ones, or those metal stocks in society, already extracted, processed, put into use, currently providing service, or discarded or dissipated over time.

The UNEP survey identified the studies of metal stocks in society from 1932 to 2007. It has been observed that aluminium is probably the most investigated material.

There are also several data gaps in the information available for materials used in large quantities. "*Anthropogenic stock estimates of the specialty metals are almost nonexistent. This situation is partly due to lack of data, partly to lack of interest in such studies*". Furthermore, available figures are affected by large uncertainties.

Potential interesting metals for future studies are the lanthanides (separately or as a group), which see extensive use in electronics and medical equipment, and indium, an element essential at present for flat-panel displays.

Table 3 illustrates a summary of principal metal reservoirs [UNEP, 2010b]. Reported columns refer to:

- Metal: typology of material;
- Reservoir: a category which groups a collection of related final goods in which a metal resides in-use;
- Predominant final goods: Major final goods within a reservoir category;
- End-use fraction: as of 2006, the weight percentage of metal produced that is an inflow for each reservoir. percentages refer to specific metal;
- Estimated residence time: amount of time (in years) that a metal will remain in stock before being discarded.

Recycling of metals represents a strategy to reduce the impacts of materials and improve resource efficiency. In the report "Recycling rates of metals" the authors state that "*in theory, metals can be used over and over again, minimizing the need to mine and process virgin materials and thus saving substantial amounts of energy and water while minimizing environmental degradation. Raising levels of recycling world-wide can therefore contribute to a transition to a low carbon, resource efficient Green Economy while assisting to generate 'green jobs*" [UNEP, 2011].

However, as estimated, the recycling rates of metals are in many cases far lower than their effective potential. Less than one-third of some 60 metals studied have an end-of-life recycling rate above 50 per cent and 34 elements are below 1 per cent recycling.

[10] U.S. Geological Survey – USGS (www.usgs.gov); British Geological Survey (BGS) (www.bgs.ac.uk)

Table 3 Specification of principal metal reservoirs (adapted from [UNEP, 2010b])

Metal Reservoir	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Estimated Residence Time (years)
Aluminium	Building & construction	Siding, window frames	25%	30 – 50
	Infrastructure	Cable used by power utilities	18%	30 – 40
	Transportation	Automotive equipment, railway equipment, aviation	28%	15 – 40
	Packaging	Beverage cans, foil	13%	0.3 – 0.8
	Other		16%	10 – 15
Antimony	Building & construction	Flame retardants	55%	10 – 30
	Transportation	Automotive equipment, railway equipment, ship building, aviation	18%	
	Chemicals		10%	
	Business durables	Ceramics and glass	7%	
	Other		10%	
Cadmium	Consumer and business durables	Batteries	81%	3
	Pigments	Business and consumer applications	10%	
	Industrial durables	Coatings and plating	7%	
	Other		2%	
Chromium	Building & infrastructure	Elevators, railways	25%	30 – 50
	Transportation	Automotive exhaust systems, railway equipment, ship building, aviation	15%	30 for planes, trains, and ships
	Household appliances & electronics	Appliances, household products	5%	15
	Metal goods & other uses	Cutlery, fasteners	30%	5 - 15
	Industrial machinery	Heat exchangers, tanks	25%	20
Cobalt	Transportation	Automotive equipment, railway equipment, ship building, aviation	43%	20 - 40
	Chemicals		26%	
	Cutting tools	Blades, disks	22%	1
	Industrial durables	Industrial (in-plant) machinery and equipment	22%	20
Copper	Building & construction	Building wire and copper tube	50%	25 - 40
	Infrastructure	Copper cable used by telecom utilities and power utilities	22%	50
	Transportation	Automotive equipment, railway equipment, ship building, aviation	5%	10 - 30
	Consumer durables	Appliances and extension cords, consumer electronics, fasteners and closures, household products	5%	10
	Business durables	Business electronics, lighting and wiring	10%	20
	Industrial durables	Industrial (in-plant) machinery and equipment	8%	20
Gold	Jewellery		85%	30 - 50
	Dental	Inlays	9%	
	Electrical and electronics	Business electronics, consumer electronics	6%	
Iron	Building & construction	Building beams, reinforcing bars	50%	30 – 50
	Transportation	Automotive equipment, railway equipment, ship building, aviation	23%	20 – 40
	Machinery and appliances	Appliances, industrial (in-plant) machinery and equipment	20%	20
	Other		7%	25
Lead	Building & construction	Lead sheet	54%	40 – 100
	Machinery and appliances	SLI batteries	21%	1 – 4
	Machinery and appliances	Stationary batteries	14%	8 – 12
	Infrastructure	Lead pipe	11%	20 – 50
Magnesium	Castings	Transport systems, components	59%	
	Alloys	Packaging, transport	28%	

Metal Reservoir	Reservoir	Predominant Metal-containing Final Goods	End-use Fraction (percent)	Estimated Residence Time (years)
Manganese	Building & construction	Structural steel	29%	30 – 40
	Transportation	High-strength steel	12%	20 – 40
	Industrial durables	Industrial (in-plant) machinery and equipment	12%	25
Mercury	Chlor-alkali production		40%	
	Manufactured products	Dental amalgams, instruments, lighting	32%	
	Artisanal gold		3%	
Molybdenum	Steel alloys	Stainless steel, superalloys	80%	
	Catalysts		8%	
Nickel	Building & construction	Alloys	9%	30 – 50
	Infrastructure		11%	30 – 50
	Transportation	Automotive equipment, railway equipment, ship building, aviation	33%	10 – 30
	Consumer durables	Appliances, consumer electronics, household products	13%	10 – 15
	Industrial durables	Industrial (in-plant) machinery and equipment	26%	20
Palladium	Transportation	Automotive equipment	57%	20 - 40
	Consumer durables	Consumer electronics, business electronics	18%	5 - 10
	Dental		14%	
Platinum	Transportation	Automotive equipment	39%	20 – 40
	Jewellery		37%	20
	Chemical catalysts	Fuel cells	5%	25
	Electronics	Consumer and business equipment	6%	25
Rhodium	Transportation	Automotive equipment	86%	20 – 40
	Glass manufacture		6%	
	Chemical catalysts	Fuel cells	6%	
Silver	Industrial applications	Electronics	Solders	44
	Jewellery, tableware		29%	20 – 40
	Photography	Film, plates	22%	20 – 40
	Coins and medals		5%	10 - 40
Stainless Steel	Transportation	Automotive, rail, ship	29%	10 – 30
	Industrial machinery		20%	20
	Building & construction		18%	30 – 50
	Electronics		7%	10
	Other		26%	15
Tin	Cans and containers		27%	
	Electrical and electronics		23%	
	Construction	Corrosion prevention	10%	30 – 50
	Transport	Corrosion prevention, solder	10%	20 – 40
Titanium	Carbides, chemicals, metal and metal alloys		3%	
Tungsten	Cutting tools		50%	1
	Lighting		22%	
Zinc	Building & construction	Galvanised steel, zinc alloys and pure zinc	48%	10 – 50
	Transportation	Motor vehicles, vehicle tires, and railway transport, sea and air transport	36%	2-20
	Business durables	Machinery	7%	
	Chemicals		5%	

1.2.3.3 Metal recycling

Another study on metal recycling is currently under development by the UNEP [UNEP, 2011b]. The study intends to analyze potential benefits and difficulties related to metal recycling.

The study notes that the benefits of recycling are usually uncontested: saving of natural resources and better environmental performance. However, these benefits depend very much on the performance of the recycling processes involved and in reality, neither of the two potential benefits must necessary be realized.

The study therefore focused on components of the products that are responsible of relevant environmental impacts and that, if recycled could grant significant benefits. *In particular electrical and electronic equipment (EEE) represents one of the most relevant product groupings*.

The demand for precious metals by manufacturers of EEE has increased significantly over the past few years. Looking at the End-of-Life, specifically in small Waste Electrical and Electronic Equipment (WEEE) due to its sizes and its specific functions, high concentrations of precious and specialty metal can be expected. Steel and ferrous metal is mainly found in large household appliances. On the other side, precious and specialty metals are not equally distributed in WEEE. For example the study observes that mobile phones and desktop personal computers account for 39% of the precious metal in WEEE[11].

Components like printed circuit boards (PCB) represent between 0 and 30 % of the mass of EEE and contain many of the minor metals used. In particular PCBs can contain various “critical” materials[12] (the mix depends on the type of application) and also other relevant materials. Table 4 gives an overview of the composition of various PCBs from various WEEE categories.

For example, on average, a PCB from a PC contains on average 7% Iron, 5% aluminium, 20% copper, 1.5% Lead, 1% nickel, 3% tin and 25% of organic materials in addition to 250ppm of gold, 1000ppm of silver and 100ppm of palladium. It is concluded that the recycling of the PCB fraction in copper-based smelter is a valuable activity.

[11] Estimation based on data for 2007 for Germany [UNEP, 2011b]

[12] The following materials can be embodied in varying concentration: Platinum Group Metals (PGM), antimony, tantalum, gallium and beryllium.

Table 4 Average composition of printed circuit board (PCB) installed into various electrical equipment [UNEP, 2011b]

	Content of motherboard in product [%]	Metal concentration in PWB (g/t PWB)				Mass of equipment [kg]
Product		Ag	Au	Pd	Pt	
Computer keyboard	2-2.1	700	70	30		
LCD monitor	4-7.8	1300	490	99		
Computer mouse	8-8.2	700	70	30		
DVD player	10-16.2	700	100	21		2.95-3.4
Hi-fi unit	8-10.6	674	31	10		4.15-5.05
Laptop	15-17.1	1000	250	110		
Speaker	2	674	31	10		
Mobile phone	22-22.1	3573-5540	368-980	285-287	7	
PC	8.9-13	600-1000	81-600	90 -110	40	
Printer/fax	6.6 -8	350	47	9		
Radio set	20-20.5	520	68	8		5.13-6.2
Telephone	21.9 -22	2244	50	241		
Video recorder	10-14	674	31	10		4.0-6.4
Audi & video		674	31			
Computer CRT Monitor		150	9	3		
Small IT and communication equipment		5700	1300	470		
TV set - CRT Monitor		280-1600	17-110	10-41		
TV set - LCD Monitor		250	60	19		
Coffee machine	0.3					
Drill machine	0.2					
Shaver	2.2					
Hair dryer	0.1					
Hand held videogame console	21.5					
Mixer / blender	0.7					
Plastic electrical toys	2.1					
Calculator	14.1					
Bread machine	2.8					
Vacuum cleaner	0.7					
Game computer	19.6					

Other relevant product groups are some large "white goods" such as washing machines, fridges, ovens, dishwashers which mainly consist of the following materials (Table 5):

- Metals (steel, copper, aluminium, stainless steel and their alloys);
- Various plastics and organic materials including their additives, fillers and stabilisers;
- Inert materials such as glass and concrete;
- Low value PCB and electronics containing PGM and precious metals.

Relevant materials (including also EU Critical Raw Materials) are present in "white goods" primarily on the PCB. Usually the large white good recycling focuses on the recovery of bulk commodity materials according to WEEE recycling guidelines. For PCBs the following holds true [UNEP, 2011b]:

- PCBs form a very small part of this recycle stream and mostly goes lost.
- If recovered, physics limits the production of clean 'recyclates' from this, which makes subsequent process in metallurgical plants difficult.
- The recycling of relevant metals in PCB has a low efficiency when these are treated by mechanical separation plants together with other commodity materials (steel, aluminium, etc).

Table 5 Average composition of "white goods" [UNEP, 2011b]

Material [%]	Washing machine	Dryer	Dish washer	Oven
Iron/Steel	52.1	68.8	45.2	81.3
Copper	1.2	2.3	1.5	0.2
Aluminium	3.1	2.1	0.8	1.9
Stainless Steel	1.9	1.2	23.2	0.7
Brass	0.1	0.1	0.2	0.5
Plastics	6.8	15.9	12.6	0.7
Rubber	2.8	0.9	1.6	0.4
Wood	2.6	4.5	2.1	0.0
Other organic	0.1	-	5.3	0.0
Concrete	23.8	-	1.9	0.0
Othe inert material	1.9	1.3	0.9	12.6
PWB	0.4	0.4	0.1	0.1
Cables (internal/external)	1.1	1.8	1.5	1.3
Other materials	2.2	0.8	3.2	0.3
Total	**100**	**100**	**100**	**100.0**

The UNEP study also identifies thermodynamic limitations in the recovery of metals as one of the main issue to deal with in the next future in order to improve resource efficiency of products. In particular, the study underlined the relevance of 'design for recycling strategies' including 'Design for Disassembly' that is recognised as an "imperative to minimize loss of valuable elements to maximize profitability of the recycling system" [UNEP, 2011b]. The design of components/subassemblies has a key impact on the efficiency of recycling/recovery. In particular, the recycling/recovery rate is dependent on "the combination and location of materials on separate and/or connected components, and will differ for different WEEE products as well as the selected recycling route and technology available".

This also applies to the recovery of EU Critical Raw Materials. For example authors state that: "*tungsten and tantalum as present in getters (in CRT TV's and lighting) can potentially be recovered when separated from the product (dismantling from getters) and processed in appropriate technology. However when processed together with the other metals, substantial losses of these elements to non-valuable phases will occur due to the stability of the oxides.[…] The same applies to various Rare Earths*" [UNEP, 2011b].

Depending on the process route followed, recovery or losses are possible for example for closely/complexly linked metals (e.g. Platinum Group Metals, precious metals and Rare Earths on printed wire boards) where the choice to recover one metal will result in the other metal being lost. This is driven by the thermodynamics and technology as well as by design considerations. Examples are shown in Table 6, which illustrate the suitability fore recycling of some relevant materials into Energy Related Products (ERP).

Similar conclusions have been also supported by other studies. For example a study published by the 'European Pathway to Zero Waste' suggests among possible strategies for the improvement of the recovery of CRMs [Oakdene Hollins, 2011]:

- "Advanced sorting techniques: Existing business models using practices such as 'shred and sort' are poor at isolating small, high value items containing critical materials. Therefore, high value materials may be lost or dispersed into large quantities of generic shredded waste. Implementation of more sophisticated sorting, which distinguishes between items containing critical materials, will help encourage the recovery of these raw materials, and produce 'higher value' waste streams".

- "Design for disassembly: Existing sorting of materials is often held back by product design lowering the ease in which parts can be separated, for instance using epoxy resins or non-standard screw types for connecting components. Adopting design practices which enable disassembly will improve the efficiency of sorting. […] This action will also help remanufacturers and refurbishers extend the life of products".

Table 6 Suitability for recycling of some relevant materials into ERP [UNEP, 2011b]

* Recovery is a function of process route, design, etc. The table gives the recovery for the present most likely route, but could change if suitable technology exists.

Recovery possible	If separately recovered and/or if there is appropriate technology and recovery available
Limited recovery / recovery under certain conditions	If separately recovered. Partial or substantial losses during separation and/or processing/metallurgy. Recovery if appropriate systems exist.
Pure recovery not possible	Pure recovery not possible. Lost in bulk recyclates during separation and/or during metallurgy into different non-valuable phases.
for a combination of colour	Depending on process route followed high recovery or high losses possible. Need carefully attention to design, infrastructure, legislation, etc. This is specially possible for metals closely linked, where one metal can be recycled while the other, due to this selection of recovery, then goes lost. This is driven by the thermodynamics, technology, design, etc.

Possible strategies on how to overcome recycling problems and to increase the overall recovery rate include:

- better collection systems,
- alloy specific sorting technologies (however liberation i.e. attachment to other materials in complex products may render in some cases this not feasible),
- improve and adapted liberation technologies,
- identification and separation of metal containing components (complex products with complex material linkages may make this superfluous),
- new mechanical, chemical and thermal separation and concentration technologies for concentration metal
- additional recovery processes for end-refining metals and metal products.

1.2.4 Summary of literature review

A summary of the literature review discussed in the previous sections is provided in Table 7

Table 7 Summary of the literature review

Study	Adopted method	Main results	Comments
[van der Voet et al., 2005]	- Multiplication of material flows within an economy by life cycle impacts; - Normalisation; - Aggregation	Identification of materials and sectors more impacting within EU-25, as: - Animal products, - Crops - Plastics - Fossil fuels for electricity	- Large uncertainties due to LCA data; - Few details on materials flows; - Subjective weighting phase
[JRC, 2006]	Economic and environmental Input/Output model.	Identification of sectors more impacting within EU-25, as: - -food and drink - private transport - housing	- Results in line with other references. - Uncertainties related to the adopted method
[UNEP, 2010]	Literature review of existing studies about impacts of products and materials	Identification (worldwide) of the: - priority list of metals based on their environmental impacts; - contribution of some sectors to global impacts	It is noticed the relevance of 'resource depletion' impact category, but the lacking of global authoritative studies on the topic
[UNEP 2010b] ; [UNEP, 2011]	Literature review of existing studies concerning the amount of stocks of metal utilized by society.	Identification (worldwide) of main end-uses of metals	- Detailed analysis of stocks (limited only to metals); - Relevance of metal recycling to reduce environmental impacts
[UNEP, 2011b]	Literature review on existing studies on recycling of metals	Identification of: - key issues concerning the metal recycling; - components into some exemplary product group that are relevant for the content of some substances (e.g. precious metals into PCB)	General discussion based on the literature with important considerations on strategies for the improvement of the recycling of metals

1.3 High level analysis of the impacts of materials and products

The next stage of the study is the development of the 'high level' environmental analysis of the impacts of materials and products.

It is noted that this 'high level" analysis does not aims at estimates precise figures of the impacts of the products, but more approximately at identifying materials and products that are potentially relevant within the European context.

The results of this 'rough' analysis will be useful for the next stages of the project, mainly the identification of relevant case-studies and the estimation of the relevance of potential ecodesign measures for products.

Following the previous literature review it results that, although several uncertainties, the study from [van der Voet et al., 2005] develops a method for the assessment of impacts of materials and products. Study from [JRC, 2006] assesses macro-sectors, while other studies are mostly based on a literature review. Therefore the method from [van der Voet et al., 2005] represents the most suitable for the current project.

However, the weighting/aggregation phase is considered too uncertain and it will be not applied in the current study. Furthermore, the report from [van der Voet et al., 2005] analyzes only the environmental impacts of a restricted set of materials and it does not provide other relevant information concerning, for example, the recycling rate or main end-uses of materials.

Therefore the method from [van der Voet et al., 2005] has been modified for the current 'high level' environmental analysis as following[13]:

- different set of materials considered;
- different sources for Life Cycle Inventories of materials (update data utilized);
- different impact categories considered;
- aggregation and weighting of impacts has been not applied;
- detailed analysis of relevant materials has been performed (including the analysis of average recycling rates and end-uses of materials, based on the results of other studies from the literature review).

The method for the current 'high level' analysis has been therefore revised and subdivided in the following steps:

a) Assessment of the consumption of materials within the EU.

b) Analysis of specific impacts of materials.

c) Assessment of the overall impacts due to material consumption.

d) Normalisation of impacts.

e) Analysis of end-uses of relevant materials.

The next sections provide a detail of each step.

1.3.1 Consumption of materials within the EU

1.3.1.1 General approach

The first part of the analysis includes the selection of materials for the 'high level' analysis. The previous references illustrated some consideration about materials generally used into products. The next section will mainly focus on materials that are used to manufacture ERPs, including[14]:

- materials from the "critical raw material initiatives" [EC, 2010]
- other materials: cadmium, gold, lead, mercury, phosphate, potash, salt, selenium, silicon, sulphur, tin;

[13] Due to the different method choices, results of the present report are not directly comparable to those from [van der Voet et al., 2005].

[14] The selection of the materials for the analysis follows the results of the literature review in Section 1.2.

- polymers (thermoplastics): ABS, EPS, PE-HD, PE-LD and PE-LLD, PA, PC, PET, PP, PS, PUR[15, 16].

Main uses and potential relevance of selected materials for ERP are illustrated in Table 8[17]. Concerning plastics, detailed figures about uses into ERP are missing. However, from the scientific literature and from the analysis of some BOMs[18], it is observed that all the selected plastics are largely used into ERP.

Afterwards, the flows of the selected materials in the EU have been roughly estimated, based on available literature as follows:

Formula 1. Flow of the material = Import + internal production – exports

The estimated flows of the materials, including data sources, are illustrated in Annex 1. In particular, internal production figures have been mostly derived from report of the British Geological Survey [BGS, 2011] and, when not available, from the reports of the US Geological survey [USGS, 2011] or other sources.

When available, data concerning imports and exports of raw materials are derived from the United Nations Commodity Trade Statistics Database [UN, 2011], or otherwise from the "Critical raw material initiatives" [EC, 2010] or from other sources. When available, flows of year 2009 have been considered; otherwise, most up-to-date figures have been considered. Concerning plastics, due to low data availability, figures refer to plastics sold in the EU (from statistics).

It is noted that the estimation of material import/exports flows as in Annex are affected by large uncertainties. In particular, only flows of ores and raw materials have been accounted and, when available, flows of semi-manufactured products. Flows of materials through finished products have been not considered due to the large difficulties of such estimation and the large amount of different products entering/leaving the EU.

In order to assess the potential errors of such approximation, it has been performed a more detailed analysis concerning two materials (copper and zinc), trying to account also quantities of such materials that enter/leave the EU though finished product. Results are illustrated in the next section.

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[15] For the acronyms of plastics, see the 'Abbreviation' section at the beginning of the report.
[16] In order to avoid potentially misleading results, the analysis did not consider the Polyvinyl chloride (PVC) due to missing updated data concerning the life-cycle inventory of this plastic.
[17] Reference for end-uses are reported in Annex 1.
[18] For example, as observed in the Bills of Materials of Ecodesign preparatory studies.

Table 8 Uses of some materials for ERP

Material	Uses and relevance for ERP
Aluminium	Largely used into building components (29%), e.g. in windows) and for technical engineering products (19%) including components of various EEE
Antimony	Main use as flame retardants (72%) for plastics, embodied into various products, including EEE. Low percentages (0.01%) used into semiconductors
Barite	3% used into electronics
Bauxite	Mostly used for the production of aluminium (see above)
Bentonite	Used for the production of iron production of building components and detergents.
Beryllium	Approximately 40% of beryllium is used for Electronic equipment and domestic appliances and Electronics and IT - due to its favourable electric conductivity
Borates	Borates are an important ingredient for the production of fibreglass used as insulation and also in various application (including circuit boards)
Cadmium	Cadmium is mostly used for the production of batteries (81%). Large parts of these are used into EEE
Chromium	Mostly used (95%) for the production of high quality steel used for various application (including EEE)
Clays	Mainly used for the production of ceramic. A low quantity of high purity ceramics are used into EEE.
Cobalt	Used for batteries (49%), and super-alloys and magnets (16%) for engines, turbines, and parts of motors.
Copper	Largely used for electrical (28%) and electronics (13%).
Diatomite	Small amounts (2%) used for insulations.
Feldspar	Used for the production of glass (embodied into various ERP)
Fluorspar	Used for the production of Aluminium and Steels.
Gallium	Almost the totality of Gallium is used into the electronic industries.
Germanium	15% are used for electric and solar electric applications (solar cells, LEDs, photo-detectors)
Gold	9% used into EEE
Graphite	12 % used into Electrical application. Larger amount used for the production of steels.
Gypsum	Largely used into construction sector, including wallboard and insulation panels.
Indium	Used for display panels (74%) for high-tech products (photovoltaic, LCD). 2% used for semiconductors and LED
Iron	Used in several ERP (no detailed figures available)
Lead	80% used into batteries
Limestone	Used for the production of metals as iron, steel, zinc, lead, copper and antimony.
Lithium	20% is used for batteries. 0.2% is directly used into electronics
Magnesium and magnesite	50% of Magnesium is used for magnesium alloys used into various applications (including EEE)
Manganese	Largely used for the production of steel. 2% is used for dry cell batteries.
Mercury	3.8% used into batteries; 3.1% in lamps.
Molybdenum	Mainly used for the production of steel. 2% used for lubricants.
Nickel	Mostly used for the production of steel. 3% used into batteries.
Niobium	Mainly used for the production of ferro-nyobium steel. Small amount used for magnets, superconductors and capacitors
Perlite	60% used for insulations in the construction sector
Phosphate	Used into detergents (below 10%)
Platinum (PGM)	11% used into Electric and electronics (capacitors, thermocouples, hard drives)
Potash	Low relevance (used to produce some chemicals embodied into EEE)
Rare Earth	19% used in magnets for high efficiency motors. Other applications includes also the production of capacitors and lasers and their use in several innovative technologies
Rhenium	70% of rhenium is used as an important component in superalloys for blades in turbine engines.
Salt	Used for the production of various chemicals
Silica-sand	Used for the production of glass, largely used into EEE and construction components
Selenium	35 into electronics
Silicon	8% electronics
Silver	Electrical/Electronics (contacts) 23%
Sulphur	Low relevance
Talc	18% used for the production of plastics for various products including electrical appliances.
Tantalum	60% used in capacitors
Tellurium	26% used in PV cells; 11% used into other electronics
Tin	28% used into electrical equipment
Titanium	Largely used for paints used for various applications (including ERP)
Tungsten	Tungsten wires, electrodes and contacts are used in lighting, electronic, electrical, heating applications
Vanadium	Largely used to produce special steels for different application
Zinc	Consumer goods & electrical appliances (23%)

1.3.1.2 Application to zinc and copper

In order to assess the uncertainty of Formula 1, a more detailed estimation of mass flows of copper and zinc within EU has been calculated taking also into account the quantities of these materials that enters/leaves the EU because embodied into imported/exported goods. Based on references, it has been estimated the average content of copper into EEE and vehicles[19] and the average content of zinc into EEE, vehicles and galvanized steel[20]. Calculations have been referred to the year 2005 and 2009.

The overall flows of copper and zinc are illustrated in Figure 4. It is noted that, for both these two considered materials, the amounts of mass entering/leaving the EU through the considered products/semi-products have a low relevance compared to the quantity of copper and zinc that enter/leave EU through refined/unrefined alloys and ores.

Therefore it is assumed that approximated calculations according to Formula 1 have a sufficient precision for the scopes of the 'high level' assessment of the present study.

On the other hand, it is observed a large variability of flows of materials between the two considered years. This has been also confirmed by figures concerning other materials. In general, consumption during 2009 results largely lower than that related to previous year, probably related to the economic crisis of the past years. Uncertainties related to the consider time-frame can be relevant, and therefore, results are representative of the considered reference year/s.

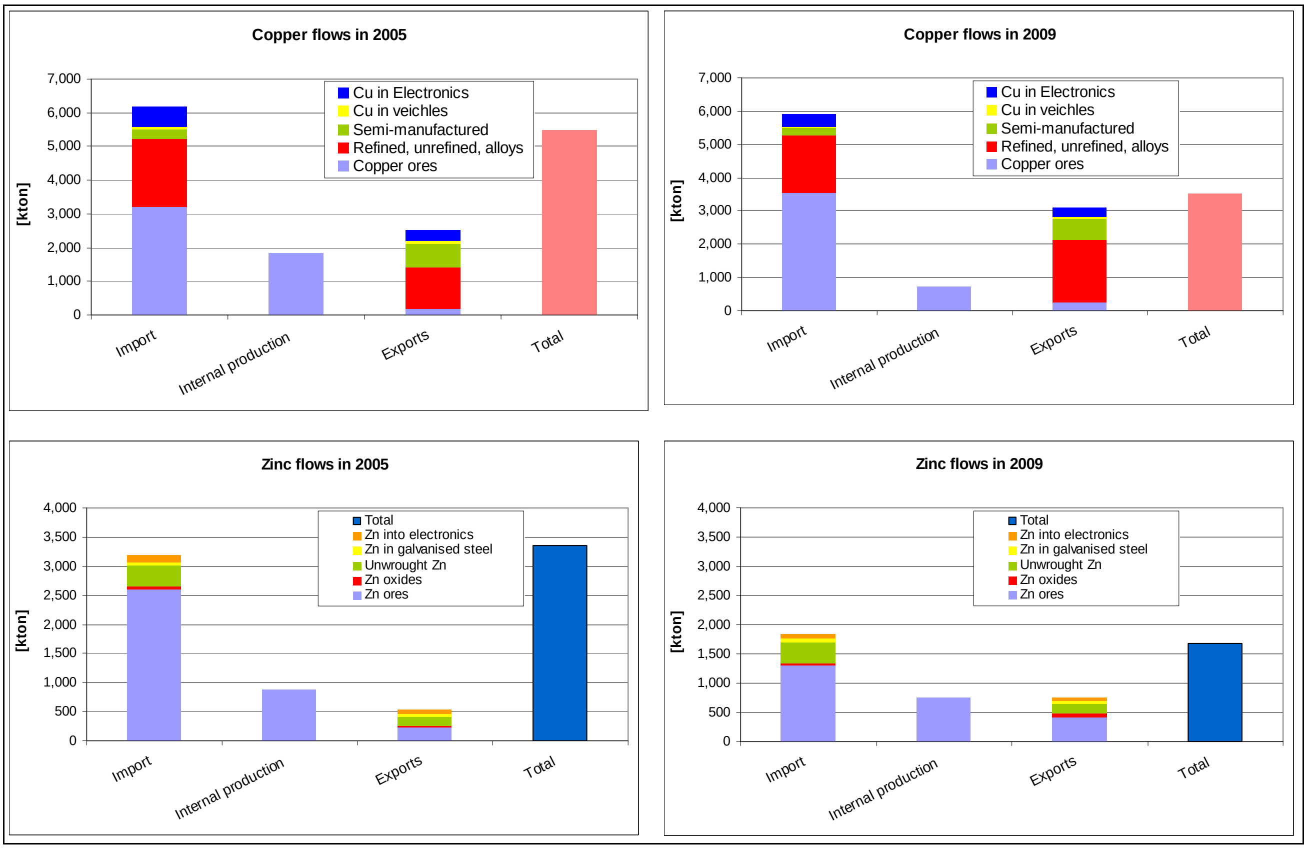

Figure 4. Estimation of flows of copper and zinc in the EU (years 2005 and 2009)

[19] According to [Bertram et al., 2002], it has been assumed that: average copper content of EEE is 4.6%; average copper content of small vehicles is 1.4%; average copper content of large vehicles is 0.5%.

[20] According to [Spatari et al., 2003], it has been assumed that: average zinc content of EEE is 1%; average zinc content of vehicles is 4%; and average zinc content of galvanizes steel is 4%.

1.3.2 Specific environmental impacts of materials

The next step of the analysis is the collection of life cycle data of materials following a cradle-to-gate approach. Data refer to production of primary materials.

When available, inventory data refer to the ELCD database [ELCD, 2010]; otherwise other data sources have been used (mainly [PE, 2011; ecoinvent]) trying to select the most updated data and representative for the European geographical context.

The selection of the impact categories has been based on the basis of the criterion of the acceptance in the scientific literature: only impacts categories largely established among LCA practitioners have been considered. In particular, the selected impact categories (Table 9) referred to ILCD Handbook recommendations[21, 22, 23] [JRC, 2010]. Characterization factors refer to values implemented in LCA software [PE, 2011].

Table 9 Selected impact categories for the environmental analysis of materials[24]

Impact category	Selected LCIA method
Climate change	Global Warming Potential –(GWP) [IPCC]
Ozone depletion	Ozone Depletion Potential – (ODP)
Human toxicity effects	Human Toxicity Potential (HTP) [ReCiPe]
Particulate matter/Respiratory inorganic	Particulate Matter Formation Potential (PMFP) [ReCiPe]
Photochemical ozone formation	Photochemical oxidant formation [ReCiPe]
Acidification	Acidification Potential (AP) [CML]
Eutrophication, aquatic	- Freshwater Eutrophication (FEP) [ReCiPe] -Aquatic Eutrophication marine water - (MEP) [ReCiPe]
Ecotoxicity (freshwater)	Freshwater Aquatic Ecotoxicity Potential (FAETP) [ReCiPe]
Ecotoxicity (terrestrial)	Terrestric ecotoxicity Potential (TETP) [ReCiPe]
Land use	- Urban land occupation (ULOP) [ReCiPe] - Agricultural land occupation (ALOP) [ReCiPe]
Resource depletion, water[25]	Freshwater consumption (amount in kg)
Resource depletion, mineral, fossil and renewable	- Abiotic Depletion Potential (ADP element) [CML] - Abiotic Depletion Potential (ADP fossil) [CML]

Specific impacts per kg of materials are reported in Annex 2. Using this method, Table 10 summarizes the ranking of materials according to their decreasing environmental impacts (per unit of mass) according to the considered impact categories. Some relevant materials are:

- all the considered precious metals (as gold, silver and platinum group), which are generally the most impacting ones for almost all the impact categories;
- several EU critical raw materials (e.g. platinum, tantalum, gallium, magnesium, cobalt, indium, rare earths) for various impact categories;
- various commonly used material (as copper, chromium, molybdenum, nickel).

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[21] During the development of the project, recommended ILCD Life-cycle indicators have been revised and published (see http://lct.jrc.ec.europa.eu/pdf-directory/Recommendation-of-methods-for-LCIA-def.pdf). This revised set of indices has been not considered in the present 'high level analysis'. The 'High level analysis' should be updated in the future by integrating such advancements.

[22] The selection of the impact categories has been based also on the criterion of the availability of normalization data for the next step of the analysis (see Section 1.3.4).

[23] Other impact categories in use in other life-cycle based tools (as e.g. the CRM indicator in use in the MEErP ecoreport tool) have been not considered due to their limited use at the current stage and their lack of testing/analysis on practical examples.

[24] The characterization factors for the selected impacts refer to data implemented in the GaBi software [PE, 2011]

[25] Concerning the "water consumption" the overall amount of water from inventory data has been considered (without any characterization).

According to this method, plastics have generally lower impacts (per unit of mass) compared to raw materials.

It is noted that inventory data for various considered materials are missing, including 5 critical raw materials (Antimony, Beryllium, Germanium, Niobium, and Tungsten). These materials have been not considered in the next steps of the analysis.

It is also underlined that used data refer to different sources and inconsistencies are possible. Data quality has been considered adequate for the scopes of this analysis[26].Furthermore, large uncertainties relate to some impacts categories as water consumption and 'land use'[27]. Therefore results of Table 10 and Annex 2 have to be considered as only approximated.

It is highlighted that values in Table 10 are based on the environmental impacts (per kg of mass) due to the production of virgin materials. However, these values should be not used as basis for general 'judgments' on the materials, being the use of such materials into products not considered here. Results should also only be used within the scope of this study.

[26] It is reminded that the 'high level' analysis does not aims at estimates precise figures of the impacts of the products, but more approximately at identifying materials and products that are potentially relevant within the European context.
[27] Inventory data on land use are largely missing for several materials.

Table 10 Ranking of materials according to their impacts (per kg of mass)[28]

Material	Ranking of materials according to their impacts (per unit of mass) for the following impact categories														
	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication fresh water	Aquatic eutrophication marine water	Human toxicity	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Water consumption	Agricultural land occupation	Urban land occupation
ABS	23	29	29	n.a.	30	18	28	46	41	34	35	20	25	n.a	n.a
Aluminium	13	17	19	12	19	32	19	17	29	19	31	16	29	n.a	n.a
Baryte	44	43	44	35	46	36	44	34	32	38	21	44	23	26	28
Bauxite	52	52	49	43	36	51	49	52	48	52	52	52	46	30	29
Bentonite	41	38	40	25	40	24	40	27	28	29	29	38	n.a	24	21
Borates	48	45	43	36	35	41	43	42	40	42	13	48	42	27	24
Cadmium	39	37	37	30	39	31	38	29	23	24	2	37	34	21	22
Chromium	10	13	14	9	14	9	12	12	11	6	14	9	10	12	13
Clays	53	53	53	44	53	53	53	53	53	53	53	53	50	31	31
Cobalt	14	16	12	17	13	17	9	14	16	16	20	13	12	10	9
Copper	24	8	11	20	10	22	11	9	9	7	10	30	19	13	7
EPS	26	30	30	n.a.	32	26	29	44	39	28	39	22	21	n.a	n.a
Feldspar	50	51	50	37	51	48	50	51	43	45	41	50	41	29	26
Fluorspar	45	42	45	34	44	33	46	32	27	30	32	45	38	25	27
Gallium	5	9	7	5	9	3	5	7	7	9	12	5	5	7	10
Gold	1	2	2	1	2	2	1	1	2	2	1	1	2	1	1
Graphite	51	49	52	42	49	47	52	47	42	44	42	51	44	28	30
Gypsum	46	50	51	39	52	46	51	39	52	50	22	46	47	n.a	n.a
HDPE	35	35	35	n.a.	37	44	35	49	22	48	49	25	36	n.a	n.a
Indium	6	5	5	7	6	7	6	4	8	4	6	6	6	5	6
Iron	29	32	32	21	33	27	31	22	25	40	43	42	n.a	n.a	n.a
LDPE / LLDPE	33	34	34	n.a.	34	40	33	48	45	46	40	27	33	n.a	n.a
Lead	36	19	28	28	22	38	36	30	35	31	9	35	37	n.a	n.a
Limestone	38	48	47	41	50	42	47	35	49	36	50	41	43	n.a	n.a
Lithium	11	15	15	10	15	15	15	13	14	14	19	10	8	11	16
Magnesium	8	25	18	15	21	10	16	18	18	17	28	15	13	6	17
Manganese	30	23	24	29	25	39	24	24	33	27	30	29	27	n.a	n.a
Mercury	7	7	8	6	8	14	8	10	4	1	7	7	14	17	12
Molybdenum	12	12	9	18	7	11	7	8	10	10	8	11	9	9	5
Nickel	19	3	6	16	4	19	21	15	6	15	17	19	15	15	14
PA	16	22	20	n.a.	24	8	14	37	26	33	33	12	11	n.a	n.a
PC	18	24	22	n.a.	26	12	23	38	30	21	26	18	28	n.a	n.a
Perlite	37	40	38	23	41	35	37	32	31	37	36	36	35	22	23
PET	27	28	27	n.a.	28	50	26	40	37	25	46	24	30	n.a	n.a
Phosphate	49	47	48	40	48	52	48	45	50	47	37	49	45	n.a	n.a
Platinum (PGM)	2	1	1	2	1	1	2	2	1	3	3	2	1	2	2
Potash	32	33	33	24	29	29	32	25	20	22	27	34	26	20	19
PP	34	36	36	n.a.	38	21	34	50	46	49	47	26	32	n.a	n.a
PS	21	25	26	n.a.	27	25	25	43	38	26	38	17	20	n.a	n.a
PUR	22	26	25	32	23	13	22	23	21	23	22	21	16	23	25
Rare Earth	9	11	10	8	11	6	10	6	12	12	16	8	7	8	11
Salt	47	44	42	38	45	49	41	41	51	51	25	47	48	n.a	n.a
Selenium	31	14	23	11	16	23	27	16	17	18	18	32	18	16	18
Silica-sand	43	46	46	31	47	45	45	36	47	43	51	43	40	n.a	n.a
Silicon	15	21	16	13	20	37	17	26	34	32	34	28	31	n.a	n.a
Silver	3	4	3	3	3	5	3	3	3	5	4	3	4	4	3
Sulphur	40	39	41	33	43	34	42	28	36	35	45	33	49	n.a	n.a
Talc	42	41	39	27	42	43	39	33	44	41	48	39	39	n.a	n.a
Tantalum	4	6	4	4	5	4	4	5	5	8	11	4	3	3	4
Tellurium	17	10	13	19	12	20	13	11	13	11	5	14	17	14	8
Tin	28	31	31	22	32	28	30	21	24	39	44	40	n.a	n.a	n.a
Titanium	20	20	21	14	18	16	20	20	15	20	24	23	22	19	20
Zinc	25	18	17	26	17	30	18	19	19	13	15	31	24	18	15

Ranking:

	1 - 10
	11 - 20
	21 - 30
	31 - 40
	over 40
n.a.	not available

[28] Please, note that this table is based on the environmental impacts (per kg of mass) due to the production of virgin materials. However, these values should be not used as basis for general 'judgments' on the materials, being the use of such materials into products not considered here.

1.3.3 Impacts due to materials consumption

This step of the analysis consists in the calculation of the environmental impacts due to the consumption of materials in the EU.

Figures of consumption of materials (Annex 1) have been multiplied by available impacts data (Annex 2). Overall impact figures are not reported here.

1.3.4 Normalisation of impacts

The normalization phase has the scope to assess the relevance of some impacts compared to overall figures impacts. In this study, the normalization has been referred to the EU context.

In the absence of publically available normalization factors recommended by ILCD[29], normalization factors for the considered impact categories are illustrated in Table 11.

Table 11 Normalization factors for the considered impact categories[30]

Impact category	Climate change	Acidification	Respiratory effects	Ozone depletion	Respiratory effects	Aquatic eutrophication fresh water	Aquatic eutrophicatio n marine	Human toxicirty	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Water consumption	Agricultural land occupation	Urban land occupation
Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil	water consumption	ALOP	ULOP
Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC-11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB to urban air	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ	kg	m2*yr	m2*yr
Normalisation factor	4.9E+12	2.7E+10	2.6E+10	8.7E+07	8.1E+09	3.5E+08	5.9E+09	3.4E+10	5.0E+11	4.7E+10	8.2E+07	3.1E+13	n.a.	2.1E+12	1.9E+11
References	CML 2009 - EU25	CML 2009 - EU25	Recipe (revised 2010) EU 25+3	CML 2009 - EU25	Recipe (revised 2010) EU 25+3	Recipe (revised 2010) EU 25+3	Recipe (revised 2010) EU 25+3	Recipe (revised 2010) EU 25+3	CML 2009 - EU25	CML 2009 - EU25	CML 2009 - EU25	CML 2009 - EU25	n.a.	Recipe (revised 2010) EU 25+3	Recipe (revised 2010) EU 25+3

Normalized impacts have been calculated. Results are presented in Table 12 and Table 13. It is possible to observe that:

- Various materials are very relevant for the "human toxicity" and "abiotic depletion" impact categories.
- Plastic are generally relevant for the energy
- None of the investigated materials is relevant for the ozone depletion category
- Few materials are potentially relevant of the land use categories (however, large uncertainties are related to data availability for these categories).

[29] It his highlighted that JRC is currently developing normalization factors for the ILCD impact categories. The High Level Assessment should be updated in the future integrating the results of this ongoing research.
[30] The normalization factors for the selected impacts refer to data implemented in the GaBi software [PE, 2011].

Table 12 Normalized impacts of materials

	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication (fresh water)	Aquatic eutrophication (marine water)	Human toxicity	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Agricultural land occupation	Urban land occupation
Aluminium	1.0%	0.9%	0.3%	0.0%	0.6%	0.0%	0.5%	4.1%	0.0%	0.3%	0.0%	1.4%	0.0%	0.0%
Baryte	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bauxite	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bentonite	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Borates	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
Cadmium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%
Chromium	0.2%	0.1%	0.1%	0.0%	0.2%	0.1%	0.1%	1.4%	0.4%	2.2%	0.3%	0.4%	0.0%	0.0%
Clays	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cobalt (*)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Copper	0.3%	7.1%	1.2%	0.0%	6.6%	0.1%	1.4%	23.5%	4.2%	16.0%	8.7%	0.5%	0.0%	4.5%
Feldspar	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fluorspar (*)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gallium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gold	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	1.0%	0.2%	0.2%	9.5%	0.1%	0.0%	0.4%
Graphite (*)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gypsum	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.5%	0.1%	0.0%	0.0%
Indium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iron	5.3%	2.9%	1.8%	0.0%	2.2%	1.1%	2.4%	30.7%	1.3%	0.2%	0.0%	0.9%	0.0%	0.0%
Lead	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%
Limestone	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.1%	0.0%	0.3%	0.0%	0.0%
Lithium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Magnesium (*)	3.0%	0.2%	0.1%	0.0%	0.2%	0.2%	0.3%	1.2%	0.1%	0.2%	0.0%	0.6%	0.2%	0.1%
Manganese	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Mercury	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.0%	0.1%	0.0%	0.0%	0.0%
Molybdenum	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.1%	0.6%	0.1%	0.2%	3.5%	0.0%	0.0%	0.3%
Nickel	0.0%	0.5%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Perlite	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Phosphate	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Platinum (PGM *)	0.2%	40.2%	2.9%	0.0%	22.7%	0.1%	0.1%	2.2%	7.6%	0.2%	2.2%	0.4%	0.0%	0.1%
Potash	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%	0.4%	0.1%	0.1%	0.0%	0.2%	0.0%	0.0%
Rare Earth (*)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Salt (NaCl)	0.1%	0.1%	0.2%	0.0%	0.2%	0.0%	0.4%	0.2%	0.0%	0.0%	1.0%	0.2%	0.0%	0.0%
Silica-sand	0.4%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.6%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%
Selenium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Silicon	0.2%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
Silver	0.1%	0.3%	0.2%	0.0%	0.3%	0.0%	0.4%	1.3%	0.4%	0.1%	20.0%	0.2%	0.0%	0.4%
Sulphur	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%
Talc	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tantalum (*)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tellurium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%
Tin	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Titanium	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.1%	0.3%	0.2%	0.1%	0.0%	0.2%	0.0%	0.0%
Zinc	0.1%	0.3%	0.1%	0.0%	0.3%	0.0%	0.2%	0.9%	0.1%	0.7%	1.3%	0.2%	0.0%	0.1%

Impact <0.1%	Potentially negligible
Impact [0.1%: 1%]	Potentially relevant
Impact [1%: 5%]	Relevant
Impact [5%: 10%]	Relevant
Impact > 10%	Largely relevant

Table 13 Normalized impacts of polymers

	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication (fresh water)	Aquatic eutrophication (marine water)	Human toxicity	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Agricultural land occupation	Urban land occupation
ABS	0.1%	0.0%	0.0%	n.a.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	n.a.	n.a.
EPS	0.2%	0.1%	0.1%	n.a.	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.5%	n.a.	n.a.
HDPE	0.2%	0.1%	0.1%	n.a.	0.1%	0.0%	0.1%	0.0%	0.2%	0.0%	0.0%	1.2%	n.a.	n.a.
LDPE & LLDPE	0.3%	0.2%	0.1%	n.a.	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	1.2%	n.a.	n.a.
PA	0.4%	0.3%	0.2%	n.a.	0.2%	0.6%	0.6%	0.0%	0.0%	0.0%	0.0%	0.9%	n.a.	n.a.
PC	0.2%	0.1%	0.1%	n.a.	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.3%	n.a.	n.a.
PET	0.2%	0.2%	0.1%	n.a.	0.1%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.6%	n.a.	n.a.
PP	0.4%	0.2%	0.1%	n.a.	0.2%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%	1.8%	n.a.	n.a.
PS	0.2%	0.1%	0.1%	n.a.	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.5%	n.a.	n.a.
PUR	0.3%	0.2%	0.1%	n.a.	0.3%	0.2%	0.2%	1.1%	0.1%	0.1%	0.1%	0.8%	n.a.	n.a.

Impact < 0.1%	Potentially negligible
Impact [0.1%: 1%]	Potentially relevant
Impact [1%: 5%]	Relevant
Impact [5%: 10%]	Relevant
Impact > 10%	Largely relevant

Afterwards, the investigated materials have been listed on the basis of the number of criteria for which they results “very relevant”, “relevant” or “potentially relevant” (Table 14). Results of Table 14 have to be not interpreted as a strict hierarchy of most impacting materials, but an identification of materials that are potentially relevant for environmental impact at the EU level.

It is observed that copper, platinum (PGM), iron, gold, silver resulted the metals more relevant for the largest number of impacts categories. Finally among critical raw materials, PGM and magnesium resulted relevant for at least one impact categories[31].

It is also noted a general agreement with similar studies, as those mentioned in Section 1.2

However, the study’s conclusions have to be subjected to the various uncertainties of the study, here summarized:

- Large uncertainties in the estimation of the consumption figures of materials within the EU. In particular, consumption of raw materials through finished products has been not accounted (except than for the analysis of copper and zinc.
- Large variations of flows of materials during the years (in general figures of 2009 are sensibly lower than those of the past years). This can results in the under-estimation of the effective figures on the impacts of materials and products.
- Limitation on the number of included / excluded materials.
- Potential double-counting due to impacts of some materials embodied into inventory data of other materials.
- Inconsistency among inventory datasets derived from different references.
- Uncertainties related to inventory datasets and calculation of the impact categories.
- Life cycle inventory data missing for some materials (including 5 critical raw materials: Antimony, Beryllium, Germanium, Niobium, and Tungsten).
- Uncertainties related to the calculation of some indicators (human toxicity and ecotoxicity indicators) due to life-cycle inventory of process generally not up to date to consider all the involved substances.
- Uncertainties related to normalization factors (as derived from the scientific literature). Some normalization factors are missing for some of the impact categories initially selected.

[31]Note that 5 critical raw materials have been excluded from the analysis because of lacking of life-cycle inventory data. Furthermore, large uncertainties (related to consumption figure and life-cycle data) affect available data on other critical materials.

Table 14 List of materials "largely relevant", "relevant" or "potentially relevant" for some impact categories

Materials	Number of impacts categories to which the material is: Largely relevant	Relevant	Potentially relevant
Copper	3	6	3
Platinum (PGM *)	2	4	6
Iron	1	7	2
Gold	1	1	9
Silver	1		10
Aluminium		3	5
Magnesium (*)		2	10
Chromium		2	9
PUR		1	10
Zinc		1	10
Salt (NaCl)		1	7
HDPE		1	6
Molybdenum		1	6
PP		1	6
PE-LD , PE-LLD		1	5
Mercury		1	1
PC			8
Potash			8
Titanium			8
PA			7
Silica-sand			7
Silicon			7
PET			7
EPS			6
PS			6
Sulphur			4
Bentonite			3
Gypsum			3
Limestone			3
Manganese			3
Nickel			3
ABS			2
Lithium			2
Rare Earth (*)			2
Bauxite			1
Borates			1
Cadmium			1
Cobalt (*)			1
Lead			1
Tellurium			1

1.3.5 Analysis of end-uses of relevant materials

The last phase of the analysis focused on products that mainly embody materials that are relevant for their environmental analysis. In particular, the analysis has been limited to the first 17 materials[32]

[32] Materials 'relevant' or 'largely relevant' for at least one impact category.

listed in Table 14 (e.g. those which are relevant for at least one impact category). Results are illustrated in Annex 3.

It is notices that, according to the used method used, copper is one of the most relevant material in terms of environmental impacts and it is also largely used (over 40%) for EEEs.

Gold, silver and platinum group metals are other relevant materials for their environmental impacts. Their applications into electronics amount to around 10% and they are generally concentrated into some components (mainly PCBs, switches, relays and connectors).

Concerning other relevant materials (e.g. iron, aluminium, molybdenum) these are largely used in several products including ERP. However detailed figures about their use into ERP are here not available. Analogously, no detailed figures are available concerning chromium, magnesium and zinc, which are used to produce alloys embodied into several products, including ERP.

Plastics relevant for ERP include:

- PUR, largely used as insulation and embodied into several ERP as insulation panels and fridges;
- Polypropylene, high quality plastic used for several applications into ERP
- Polyethylene, largely used for packaging;

Other relevant materials are:

- Mercury, which is used for the production of batteries (3.8%), lamps for various ERP (3.1%) and switches (0.1%). The use of mercury is already regulated by the RoHS Directive;

Salt, that is largely used for the production of various chemicals but direct uses into ERP are not relevant.

1.4 Conclusions

The present chapter proposed and applied a method for a 'high level' environmental assessment to identify materials and products that can be relevant, at the European level, for some impact categories.

The analysis has been also preceded by a review of studies in the scientific literature concerning impacts of materials and products. In particular, concerning the impacts per unit of mass (Annex 2) some relevant materials are[33]:

- all the considered precious metals (as gold, silver and platinum group), which are those with the highest impacts for almost all the impact categories;
- several EU critical raw materials (e.g. platinum, tantalum, gallium, magnesium, cobalt, indium, rare earths) for various impact categories;
- various commonly used material (as copper, chromium, molybdenum, nickel).

According to the analysis, plastics have generally lower impacts (per unit of mass) compared to raw materials.

Considering, instead, the impacts due to total flows of the materials, figures generally change. Main result of the analysis is that copper, platinum (PGM), gold and silver are the materials that contribute relevantly to the majority of the considered impact category. It is estimated that about 40% of copper and about 10% of PMG, gold and silver are used for the manufacturing of ERP. In particular, these materials are generally embodied into some specific components as e.g. PCB, capacitors, resistors, transistors, wires and electrical contacts.

In many cases, metals thanks to their high value and the fact that they do not lose their properties through recycling are a key driver for recycling end-of-life products. It should be noted that metals are recycled to high rates but that minor metals or metals in very complex products might require different approaches compared to the traditional markets of the main metals.

For example, metals in PCBs can be relevant for their environmental impacts, as also confirmed by results of several studies. Recycling rates of these materials into EEE are generally low and, however, large improvement margins have been detected (see for example discussion in [UNEP, 2011b]).

It is therefore both necessary as well as beneficial to minimize loss of valuable and relevant elements to maximize the efficiency of the recycling/recovery. On such purpose, the design of the product play a key role by selecting the combination of used materials and the location of materials on separate and/or connected components. Based on the technologies available, manufacturers should also identify the possible recycling routes of the ERP already at the design stage.

Iron also results one of the most relevant materials. However, its uses are largely variable and, furthermore, recycling rates are already high.

some thermoplastics (PP, HD-PE , PUR, PE-LD, PE-LLD, resulted as "relevant" or "potentially relevant" for various impact categories.

[33] It is highlighted here that the following conclusions are based on the environmental impacts (per kg of mass) due to the production of virgin materials. However, these values should be not used as basis for general 'judgments' on the materials, being the use of such materials into products not considered here.

Among critical raw materials, only PGM and magnesium resulted relevant for at least one impact categories. However it is noticed that life cycle impacts of CRMs have a large uncertainty, and furthermore, data are missing for 5 CRMs: antimony, beryllium, germanium, niobium, tungsten. It is expected that relevance of CRMs into EU impacts would grow in the next decades according to the foreseen increase of consumptions.

Finally, it is reminded that the current high level' environmental assessment does not pretend to be an exhaustive and comprehensive analysis but it aims more approximately at identifying materials and products that are potentially relevant within the European context. Results and conclusion are affected by various limits, as discussed in Section 1.3.4.

2. Selection of the case-studies

2.1 Introduction

The methods developed during the project are expected to be applied to two exemplary case-study products. The selection of the case-studies represents a critical issue being it the basis for all the next project's phases.

A "case-study selection" task has been introduced. This phase consists in a preliminary screening of product groups (belonging to ErP and/or potentially 'Non-ErP'). The outcome is the identification of products suitable for potentially relevant ecodesign requirements on the investigated resource-efficiency parameters.

The case-study selection is based on the following steps:

- Definition of criteria for the selection.
- Definition of a preliminary list of potential case-study product-groups
- Application of the criteria to the potential case-study product-groups
- Identification of a short list of potential case-study product-groups
- Selection of the two case-studies.

These phases will be discussed in detail in the following sections.

2.2 Definition of criteria for the selection

The following paragraphs illustrate the criteria for the selection of the case-studies. Criteria have been identified and agreed by the steering committee of the project.

The criteria have been grouped into three areas ("A", "B" and "C") according to their subject.

A. Relevance of the case-study within the ecodesign policies.

The selection of the case-studies should focus on products potential relevant for the European ecodesign policies, including their relevance for the Ecodesign Directive. A criterion is therefore suggested.

Criterion 1. Relevance of the case-study within the ecodesign policies. The scope of this criterion is to point out product groups already identified as relevant into official European documents related to the Ecodesign directive 2009/125/EC. A product group is considered:

a. "*suitable*" for the criterion if it has been included to the Working Plan 2009-2011 or to the list of priority products for the transitional period 2005-2008[34] and if implementing measures have been not adopted[35].

b. "*potentially suitable*" for the criterion if it is part of the now wider scope of Ecodesign, now including Energy related Products or if it is a product category for which Ecodesign implementing measures have been already adopted.

c. "*not suitable*" for the criterion if it does not belong to the above categories "a" and "b".

B. <u>Relevance of the case-study for ecodesign requirements.</u>

The scope of the case study is to identify and test how potential relevant Ecodesign requirement for ErP concerning the following parameters: reusability/recyclability/recoverability (RRR); recycled content; use of priority resources; use of hazardous substances; durability, could be measured and verified. Therefore, the selection of the cases-studies should evaluate their suitability for potential relevant requirements. Five criteria have been therefore introduced.

Criterion 2. <u>Relevance of the case-study to potential requirements on Reusability / Recyclability/Recoverability</u>. The selected case-study product group should be constituted by components that are potentially reusable/recyclable/recoverable. Recyclable components are those constituted by recyclable materials[36]and that can be disassembled / separated at the End-of-Life (EoL). Energy recoverable components are those constituted by combustible materials (mainly polymers and cellulose-based materials as wood, paper and cardboard), which can be disassembled/separated at the EoL. Reusable components are those components that can be disassembled and addressed to product remanufacturing. The potential of a product category for reusing can be estimated on the basis of specific experiences of manufacturer already published in the scientific literature. A product group is considered:

a. "*suitable*" for the criterion if it is mainly constituted by one or more materials and components that are potentially recyclable / recoverable / reusable (if extractable) and it is estimated that their reuse/recycling/recovery can be relevant, on a life cycle basis, for some impact categories.

[34]During the "transitional period" between the entry into force of the Ecodesign Directive in 2005 and the adoption of the first Working Plan, implementing measures were prepared for a number of products identified as priorities by the European Climate Change Programme (Article 16 of the Directive).

[35]The scope of the project is to identify potential relevant End-of-Life requirements for ErP and should firstly focus on product categories for which implementing measures have been not adopted yet. For these products, in fact, new requirements could be potentially set only during future revisions of the implementing measures.

[36] A material is assumed as "recyclable" if there are technologies available and economically viable for their recycling. The analysis of potentially recyclable materials has been performed in Report n° 2 of the project "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive".

b. "*potentially suitable*" for the criterion if it is partially constituted by materials and or components that are potentially recyclable/recoverable/reusable (if extractable) and it is estimated that their recycling/recovery/reuse can be potentially relevant, on a life cycle basis, for some impact categories.

c. "*not suitable*" for the criterion if it is mainly constituted by materials and components that are not recyclable/recoverable/reusable.

Criterion 3. Relevance of the case-study to potential requirements on Recycled content. The previous AA1 concluded that recycled content requirements should regard materials that have a low value after the recycling, for example polymers of glass. Therefore, a product group is considered:

a. "*suitable*" for the criterion if it is largely constituted by polymers and/or technical glass (> 20% in mass).

b. "*potentially suitable*" for the criterion if it embodies some amount of polymers and/or technical glass (5% ÷ 20% in mass).

c. "*not suitable*" for the criterion if it includes small amounts of polymers and/or technical glass (< 5%).

Criterion 4. Relevance of the case-study to potential requirements on priority materials. The scope of this criterion is to focus on products that contain priority materials that are relevant for their environmental impacts at the European level[37]. Priority materials also include those identified as "critical" by the European Commission [EC, 2010]. Following these consideration, a product group is considered:

a. "*suitable*" for the criterion if embodies relevant amounts[38] of one or more materials with large environmental impacts and/or "critical raw materials".

b. "*potentially suitable*" for the criterion if it embodies small amounts of materials with large environmental impacts and/or "critical raw materials".

c. "*not suitable*" for the criterion if it does not belong to the above categories "a" and "b".

Criterion 5. Relevance of the case-study to potential requirements on the content of hazardous substances. The scope of this criterion is to focus on products that contain hazardous substances that can be object of relevant ecodesign requirements. In particular the

[37] See Task 2.1 "High level environmental assessment" of the current project that analyzes materials and products that are responsible of relevant impacts at the EU level.

[38] The estimation of the relevance of the amount relates to the expert judgment and it is based on the quantity of the material embodied into the product and the relevance of the material itself.

attention should be focused on substances that can be relevant/dangerous for the EoL treatments of the product. A product group is considered[39]:

a. "potentially *suitable*" for the criterion if it can contain hazardous substances that can be relevant/dangerous for the EoL treatments of the product
b. "*not suitable*" for the criterion if it does not belong to the above category "a".

Criterion 6. Relevance of the case-study to potential requirements on the durability. The scope of this criterion is to focus on product groups for which the maintaining of the performances over the time is a relevant issue. A product group is considered:

a. "*suitable*" for the criterion if there are evidences that a correct design of the product can grant a significant extension of the product's life-time and better overall life-cycle performances (estimation based on expert judgment).
b. "*potentially suitable*" for the criterion if it is estimated that a correct design of the product could contribute to extend the product's life-time and to improve product's life-cycle performances.
c. "*not suitable*" for the criterion if it does not belong to category "a" or "b" (especially in the case of consumable product with a very short average technical life).

C. Criteria about the complexity of the case-studies.

Case-studies too complex could be not appropriate for the development of the project's methods and could interfere with the project's deadlines. The mayor risks can be related to the data availability and the estimation of the potential computational difficulties related to the considered case-study. Two separate criteria are then suggested.

Criterion 7. Data availability. The scope of this criterion is to point out on product groups for which data are available for the analysis. In particular, data needed include the detailed Bill of Material of the product; information about the disassembly of the product. Other additional information potentially relevant is related to product's life cycle stage, including data about the manufacturing (for example for the estimation of the recycled content) or the use stage[40]. Potential data sources include studies already published in the scientific literature, private or public reports and communications from manufacturers. A product group is considered:

a. "*suitable*" for the criterion if it has been investigated in LCA studies already published in the scientific literature and technical report (including preparatory studies already

[39] Note that in this criterion product groups are only classified as "potentially suitable" or "not suitable". The category "suitable" is not used due to the large uncertainties about the effective content of hazardous substances and the assessment of their harmfulness.
[40] This information will be used to assess the relevance of the potential requirements on a life-cycle perspective.

completed) and/or if communications and reports from the manufacturers can be available[41].

b. "*potentially suitable*" for the criterion if few information on the products are available and/or if primary data from the manufacturers cannot be available.

c. "*not suitable*" for the criterion if data about the product have been not identified yet, nor data from the manufactured can be accessible.

Criterion 8. Complexity of the modelling. The scope of this criterion is to estimate potential difficulties that could arise during the analysis of the case-studies. This includes the quantity and detail of data to be modelled and the expected computational difficulties (e.g. the assessment of the impacts at the use phase or at the EoL). The assessment of the complexity of the case-study is based on the expert judgment on similar case-studies presented in the scientific literature (when available). A product group is considered:

a. "*suitable*" for the criterion if it estimated that few data are necessary and minor difficulties could arise from the analysis.

b. "*potentially suitable*" for the criterion if it estimated that several detailed data are needed and/or large difficulties could arise from the analysis.

c. "*not suitable*" for the criterion if it estimated that large amount of data are needed and/or large difficulties could arise from the analysis.

[41]It includes reports from manufacturers that are already published or private communications of manufacturers as contribution to the present research.

2.3 Preliminary list of potential case-study product groups

In order to identify a set of product-groups suitable for the case-study selection, product groups already identified as relevant by the European Commission have been considered. These include product groups in the Working plan 2009-2011, products covered during the transitional period, and products identified as suitable for the amended Ecodesign Working plan (Table 15).

Table 15 Product groups identified as relevant for the Ecodesign Directive

EuP product groups covered during the transitional period 2005-2008 [42]	EuP product groups included in the Working Plan for 2009-2011 under the Ecodesign Directive [43]	ErP potentially in the scopes of Ecodesign Directive[44]
Standby and off-mode losses (IM)	Air-conditioning and ventilation systems;	Taps and showerheads
Simple set top boxes (IM)	Electric and fossil-fuelled heating equipment;	Steam boilers/ systems
Domestic lighting (IM)	Food-preparing equipment;	Thermal insulation products for buildings
Tertiary sector lighting (street & office) (IM)	Industrial and laboratory furnaces and ovens;	Lighting control
External power supplies (IM)	Machine tools;	Window products for buildings
Electric motors (IM)	Network, data processing and data storing equipment;	Heating controls
Circulators (IM)	Refrigerating and freezing equipment;	Positive displacement/ reciprocating pumps
Televisions (IM)	Sound and imaging equipment;	Servers and storage equipment
Domestic refrigeration (IM)	Transformers;	Detergents
Boilers and combi-boilers (gas/oil/electric)	Water-using equipment.	Mobile power generation sets
Water heaters		Stationary agricultural equipment
Personal computers (desktops and laptops) & computer monitors		Elevators, escalators and moving walkways
Imaging equipment (copiers, faxes, printers, scanners, multifunctional devices)		Logistic equipment
Airco and ventilation (residential)		Mobile phones
Commercial refrigeration (display cabinets and vending machines)		Electric kettles/ Water cookers
Domestic dishwashers (IM)		Mobile agricultural machinery
Domestic washing machines (IM)		Non-domestic hot beverage equipment
Solid fuel small combustion installation		Base station subsystems
Laundry driers		Home audio products
Vacuum cleaners		Mobile construction machinery
Complex set top boxes		
Networked standby losses of energy using products		
Electric Pumps		
Fans (IM)		
note: (IM) Implementing measures already developed		

[42] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/files/productgroups_transitionalperiod_en.pdf

[43] Communication from the Commission to the Council and the European Parliament. Establishment of the working plan for 2009-2011 under the Ecodesign Directive Brussels. 21.10.2008. COM(2008) 660 final.

[44] List of ErP potentially suitable for an amended Ecodesign Working plan (from [van Elburg et al., 2011]).

Other potential relevant product-groups have been identified from other available sources, as in illustrated in Table 16.

Table 16 Additional list of potential case-study product group

EuP product groups identified as potentially priority (Priority "A") for the Ecodesign Directive[45]	EuP product groups identified as potentially priority (Priority "B") for the Ecodesign Directive [46]	Other product-groups [47]
Transformers	Machines for personal care	PV panels
Measuring transformers	Vending machines for beverage and goods	Packaging
Automatic and welding machines	Air condition systems and heat pumps	Medical equipment
Tool machines (manufacturing - industrial use)	Refrigerating equipment	
Food preparing equipment, domestic and household use	Food and drink production equipment	
Domestic equipment for clothing care and others	Surgical, patient recovery and healing equipment	
Electromechanical hand tools	Mowers	
Power electronics products (inverters, static converters, inductors, soft starters)	Cashiers and ticketing machines	
Compressors		
Electric and fossil fuels heating equipment		
Lifting, moving and loading equipment		
Industrial and laboratory furnaces and ovens		
Electro-diagnostic apparatus		
High energy diagnostic and healing equipment		
Sound and image processing machines and equipment		
Sound processing machines and equipment (including radio equipment)		
Boilers		
Generating sets using fossil fuels		
In house networking and data processing, storing and providing equipment		
Network equipment for all types of data processing (data, telecommunication, internet, mobile and radio network equipment)		
Aerials, antennas, radars, radio navigation and control systems		
End equipment for data use and communication with option of net connection		
Lighting installations not covered by existing lots		
Motor driven equipment for waste water process, hot water and chemical process		
Ventilation equipment for underground infrastructures and special processes		
Other motors or motor driven equipment not covered by lots and the above categories		

The previous tables showed that, in several cases, some product groups are very similar each other (for example groups concerning households and those related to the same typology of product for industrial purposes). In same cases, the same product category has been identified into different lists (for example for products belonging to the sound and imaging equipment).

[45] List of products of "priority A" from [EPTA. 2007]

[46] List of products from "priority A" [EPTA. 2007]

[47] Product categories that have been identified as potential relevant in some of the previous phases of the project, or that have been underlined during some meetings of the steering committee.

The list of product groups considered for the case-study selection includes:

- Air-conditioning and ventilation systems
- Heating equipment
- Food-preparing equipment
- Furnaces and ovens
- Data processing and storing equipment
- Refrigerating and freezing
- Machine tools
- Imaging and “sound & imaging” equipment
- Transformers
- Water-using equipment
- Computers & monitors
- Dishwasher / Washing machines
- Laundry driers
- Lamps
- Vacuum cleaners
- Televisions
- Set top boxes
- Electric motors (including pumps, circulators, fans)
- External power supply
- Insulation for building
- Windows
- Lighting control
- Heating controls
- Detergents
- Mobile power generation sets
- Agricultural equipment
- Elevators
- Mobile phones
- Electric kettles/cookers
- Hot beverage equipment
- Base station subsystems
- Home audio products
- Mobile construction machinery
- PV panel
- Packaging
- Medical equipment

2.4 Application of criteria for case study selection

Criteria introduced in Section 2.2 have been applied to the list of potential case-study (section 2.3). The full report of the application is illustrated in Annex 4. A partial summary of the results is presented in the next section (see Table 17), which includes products that are relevant for most of the considered criteria.

Products embodying electronic components (e.g. TC, computers, imaging equipment) are generally the most relevant concerning the RRR and the ‘hazardous substance’ criteria.

Concerning the recycled content, most relevant products are those largely constituted by plastics (e.g. imaging equipment).

Finally, concerning durability, the most relevant products are those with a longer average useful life (e.g. washing machine, refrigerators, TVs).

2.5 Case studies selection

The next step of the task regards the selection of the potentially relevant product groups for the case-studies. According to the project’s steering committee, it has been noticed that:

- the case-study products should be relevant or potentially relevant for the ecodesign policies;
- the selection should focus on product groups that are “suitable” for the largest number of criteria, avoiding product groups that are “not suitable” for some criteria

The selection should also take in to particular consideration the potential difficulties that could arise from the case-study. Cooperation with manufacturer could help to overcome these difficulties;

The selection of the case-studies has been therefore restricted to 7 possible product groups, as illustrated in the Table 17.

Among these, the product groups “washing machines/dishwasher” and “imaging equipment” (and/or “televisions”) have been considered the most suitable for the scopes of the project.

Furthermore, being these only “potentially suitable” for “recycled content” requirement, it has been decided to focus on the additional category of the “imaging equipment” concerning only the recycled content parameter[48].

[48]The analysis of the imaging equipment product category will be only a simplified case-study based on data available in the preparatory studies.

Table 17 Short list of product group for the case-study selection

Criteria		Imaging and sound & imaging equipments	Dishwasher / Washing machines	Televisions	Vacuum cleaners	Laundry driers	Computers & monitors	Air-conditioning and ventilation systems
		Product group						
A.1	Relevance to policies	Included in the WP 2009-11.	IM developed	IM developed	Product group covered during the transitional period	IM close to be published	Product group covered during the transitional period	Included in the WP 2009-2011
B.2	Relevance for "RRR" Req.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components possible	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Mostly constituted by recyclable materials. Disassembly at EoL potentially relevant. No evidence for reuse.
B.3	Relevance for "recycled content" Req.	Plastics represent a significant portion of product mass (even up to 40-50%)	Plastics represent about 15% of product's mass. Small amounts of glass	Plastics and glass detected (their amount depends on the considered technology)	Product mainly made by various plastics (over 50% in mass).	Plastics (mainly PP and ABS) around 20% in mass.	Plastics can represent a significant portion of product mass (40-50%)	Plastics (mainly PP) account for about 15%.
B.4	Relevance for "use of priority materials" Req.	Several priority materials detected, including critical raw materials and various high impact materials.	Large amount of steels. Presence of copper	Use of critical raw materials and high impact materials detected.	No priority materials detected.	Relevant amount of steels. Low amount of copper. Relevant materials into electronics (5% in mass)	Several priority materials detected, including critical raw materials and various high impact materials.	Some relevant materials into electronic components and compressors
B.5	Relevance for "use of hazardous substances" Req.	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics
B.6	Relevance for "durability" Req.	Life-time of products not long. Products often discarded due to technological development. Product upgrade possible	Product with a generally long useful life; design for maintenance can sensibly affect performance	Potential life-length very variable. Design for maintenance relevant	Potential life-length very variable. Design for maintenance potentially relevant	Product with a generally long useful life; design for maintenance can affect performance	Life-time of products not long. Products often discarded due to technological development. Product upgrade possible	Product with a long useful life; design for maintenance can sensibly affect performance
C.7	Data availability	Preparatory study available. Few data on disassembly (some available in the literature e.g. printers)	Preparatory study available. No data on disassembly. Possible cooperation with manufacturer	Preparatory study available. No dat on disassembly. Possible cooperation with manufacturers	Preparatory study available (some LCA published).Few data available on disassembly	Preparatory study available. Few data available on disassembly	Preparatory study available. Some studies in the literature. No data on disassembly.	Preparatory study available. Few LCA publication on the sector. No data on disassembly.
C.8	Computational complexity	Complex product group (several components) with various technologies	Products generally complex (several components).	Potential complex for number of components and technologies	No particular difficulties foreseen.	Products generally complex (several components).	Very complex products (computer + monitors)	Complexity of data required and their modeling

Legend

- Suitable for the criterion (orange)
- Potentially suitable for the criterion (yellow)
- Not suitable for the criterion (white)

2.6 Conclusions

The previous sections illustrate the procedure for the selection of case studies, in order to identify products suitable for potentially relevant ecodesign requirements on the investigated resource-efficiency parameters. For such purpose, eight criteria have been developed concerning:

- Relevance within the ecodesign policies
- Relevance for ecodesign requirements
- Complexity of the case-studies

Criteria have been applied to a preliminary list of 36 product groups (mainly ErP, but including also some 'Non-ErP').

Afterwards it has been accomplished a screening of case-studies focusing to product groups:

- relevant for the ecodesign policies;
- "suitable" for the largest number of criteria, avoiding product that are "not suitable" for some criteria
- Not affected by computational problems and/or lack of data.

The outcome of the analysis is the selection of the two case-studies:

- washing machines;
- televisions.

Furthermore, the "imaging equipment" category will be investigated but focusing only to the analysis of the "recycled content" parameter (see section 2.5).

3. Analysis of ecodesign requirements

3.1 Introduction

The present chapter analyses some Ecodesign requirements as introduced in the criteria for the EU Ecolabel or discussed in the scientific literature. The objective of the survey is to identify and discuss typologies of requirements potentially suitable for parameters analysed in the project (RRR, use of relevant resources, recycled content, use of hazardous substances and durability).

The current analysis is a follow-up of the analysis already carried out in the 'Ecodesign Phase 1 (EP1)' project[49] [JRC, 2011].

A qualitative discussion of costs / benefits related to the potential application of the requirements is also introduced.

3.2 Review of potential ecodesign requirements

3.2.1 Ecodesign requirements in the Ecolabel criteria

This section illustrates ecodesign requirements concerning the ecodesign parameters studied by the present project, as introduced in criteria for the EU Ecolabel[50].

The requirements have been here subdivided into:

- requirements already enforced for the labelling of some ErPs (Table 18);
- requirements already enforced for the labelling of some non-ErPs (Table 19);
- draft requirements, currently under discussion, for the potential labelling of additional product categories (both ErP and non-ErP - Table 19).

From the analysis of the Ecolabel criteria, it is observed that:

- criteria about RRR are generally introduced for some product groups (e.g. computers, televisions and imaging equipment). In particular, some are focusing on the Design for disassembly, stating e.g. that: "*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*"

[49] EP1 – Report n° 1 section 1.7 and Report n° 2 chapter 7.
[50] It is highlighted that Green Public Procurements (GPP) criteria are currently developed jointly with Ecolabel criteria, and based on a common environmental assessment of the product group. The present analysis has been focused on the survey of Ecolabel criteria only.

- a criterion about minimum threshold for RRR is introduced for the office buildings (discussed below);
- a criterion about the reusability of toner cartridges is under development for imaging equipment products;
- criteria about the use of recyclable and reusable materials are largely introduced for the packaging of several products groups. In some cases, it is requested the provision of information about the EoL of the product and its packaging in order to improve their recycling.
- the analyzed criteria generally introduced requirements on the use of hazardous substances. Generally they introduce restrictions of the use of certain metals (especially mercury, when present) and of other hazardous substances (substances regulated by the European legislation, and/or substances belonging to a provided list, and/or substances characterized by some risk phrases). It is highlighted that several requirements focus on the restriction of hazardous substances;
- In several cases, requirements about the recycled content are introduced for the packaging of the products. However, some thresholds for the recycled content of some product's parts are introduced for computers (10% use of post consumer plastics), wooden products (flooring and furniture) or hard floor coverings (70% recycled material used). Some additional criteria on recycled content are also under development for imaging equipment, office buildings and newsprint.
- Criteria on durability are also introduced for various product groups. In particular criteria about durability can be divided in the following sub-categories:
    - o Standard based requirements (when standards are available as for lamps, wooden furniture, footwear, paints and varnishes, mattress);
    - o Design for disassembly of the product for the purpose of undertaking repairs and replacements of worn out parts (as for computers, televisions, imaging equipment, water taps and toilets)
    - o Increased warranty time (as for televisions, imaging equipment, water taps and toilets);
    - o Availability of spare parts (after the product selling) for a minimum time frame;
    - o Instructions and information for users about how to carry-out the maintenance of the product and good practises to increase the product life-time;
- Criteria concerning the restriction of the use of some relevant materials are very few, including some restriction on the use of antimony in the product (as in mattress, textile products and textile floor coverings)[51]. Concerning portable and desktop computers, it is established the criterion of PCBs easy to be disassembled (to allow the recovery of precious metals)[52]. For several wooden product groups it restrictions of the use of some woods are introduced. Finally the draft criteria for office building introduced a criterion for the promotion of the use of materials with low environmental impacts.

[51] Such criteria are also related to the potential hazardousness of the substance.
[52] In some Ecolabel criteria, precious metals are recognized as relevant materials for the life-cycle of the product. It is also highlighted that such criteria are also linked to previous criteria on recyclability of the product.

Particular interesting is the draft requirements of material recovery potential for office building [Larriba et al., 2012]. It is possible to observe that, although a method for the calculation is not defined, the procedure for the calculation and verification is very close to that developed by the current project in the guidance documents (Report n° 3).

Draft Requirement. Material recovery potential of the construction components

At least 80% in weight of the waste generated at the construction phase and the end of the service life of the building shall be prepared for being re-used, recycling and other material recovery, including backfilling operations. The waste shall be used to substitute other materials, of non-hazardous construction and demolition waste […].

Assessment and verification::

The applicant shall provide a detailed description of the methodology to calculate the estimated material recovery potential of the construction and demolition waste […]. Material recovery potentials should not be hypothetical but based on exiting technologies, economic viability and applicable industry standards. In the description the applicant shall:

- identify the potentially recyclable, reusable and/or recoverable materials,
- explain how these materials could be identified and collected during the construction and demolition processes,
- describe the best today technology to recover the construction materials.

Finally, the applicant shall calculate the percentage in weight that the recycled, reused and/or recovered material represents in relation to the total amount of waste generated or estimated to be generated in each phase respectively.

Also requirements on disassemblability of the whole product or some components are relevant for the purpose of the current project. For example it is following illustrated the criterion about disassemblability of PCBs in computers [EC, 2011].

Criterion for notebook computer. Design for disassembly

[…] circuit boards, and/or other precious metal-containing components, shall be easily removable using manual separation methods both from the product as a whole and from specific components (such as drives) that contain such boards to enhance recovery of high value material […]

Assessment and verification:

A test report shall be submitted with the application detailing the dismantling of the notebook computer. It shall include an exploded diagram of the notebook computer, labelling the main components as well as identifying any hazardous substances in components. It can be in written or audiovisual format. Information regarding hazardous substances shall be provided to the awarding competent body in the form of a list of materials identifying material type, quantity used and location.

Table 18 Ecodesign requirements in Ecolabel criteria for ERP

	Product group	Criteria Date	Criteria about: Reusability	Recyclability	Recoverability	Recycled content	Use of priority resources	Use of hazardous substances	Durability
ERP	Personal Computers	9/6/2011	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 post-consumer 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)
	Portable Computers	6/6/2011							
	Televisions	12/3/2009	-	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	6/6/2011	-	-	-	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.
	Heat pumps	9/11/2007	-	-	-	-	-	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	-

Table 19 Ecodesign requirements in Ecolabel criteria for non-ERP

	Product group	Criteria Date	Criteria about						
			Reusability	**Recyclability**	**Recoverability**	**Recycled content**	**Use of priority resources**	**Use of hazardous substances**	**Durability**
non-Energy Related Products (non-ERP)	All purpose cleaners Hand dishwashing detergents Laundry detergents	28/06/2011 24/06/2011 28/04/2011	partially considered the reusability of the packaging by the 'weight utility ratio' (WUR)	identification (marking) of different parts of the packaging for recycling,	-	information of recycled content of packaging (that enters in the calculation of WUR)	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	Dishwashing detergents	28/04/2011	-	identification (marking) of different parts of the packaging for recycling,	-	Cardboard packaging (minimum 80% recycled)	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	Soaps, shampoos and hair conditioners	21/06/2007	Partially considered the reusability by the weight/Content Relationship (WCR)	identification (marking) of different parts of the packaging for recycling,	-	Recycled content of packaging enters in the calculation of WUR	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	textile products	9/07/2009	-	-	-	Criteria on the use of recycled fibres	amount of antimony in the polyester fibres shall not exceed 260 ppm.	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	Footwear	9/07/2009	-	-	-	recycled content of packaging: cardboard (100% recycled); plastics (75% recycled or biodegradable)	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Criteria on Flex resistance, Tear strength, Abrasion resistance and Sole adhesion, for various parts of the footwear (measure according to EN standards)
	Indoor and outdoor paints and varnishes	13/08/2008	-	-	-	-	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Criteria on Resistance to water, Wet scrub resistance and abrasion (measured according to EN and ISO standards)

	Product group	Criteria Date	Criteria about Reusability	Recyclability	Recoverability	Recycled content	Use of priority resources	Use of hazardous substances	Durability
non-Energy Related Products (non-ERP)	Wooden floor coverings	26/11/2006	Packaging should be made by easily recyclable material, or materials taken from renewable resources, or materials intended to be reusable.			Recycled wood accounted in the calculation of energy consumption of the floor coverings	cork, bamboo and virgin wood must originate from forests that are managed according to sustainable forest management.	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Information to be provided (recommendations for the use and maintenance of the product)
	Textile floor coverings	30/11/2009	-	-	-	Information for the use of recycled fibres	The amount of antimony in the polyester fibres shall not exceed 260 ppm.	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Information to be provided (recommendations for the use and maintenance of the product)
	Hard floor coverings	9/7/2009	Paperboard used for the packaging should be designed for reuse or be made out of 70 % recycled materials	-	-	(see criteria for reusability)	Limitation of the use of certain soils (as classified according to the European Soil Bureau's indications)	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	recommendations for the use and maintenance of the product.
	Wooden furniture	30/09/2009	Information on how to handle the EoL of the product	The product must be easily recyclable. Information on how to handle the EoL of the product	Information on how to handle the EoL of the product	Criteria pushing for use of recycled wood	Restriction of use of certain woods	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Adoption of EN durability standards; criteria on the maintenance including availability of spare parts for 5 years
	Soil improvers Growing media	3/11/2006 15/12/2006	-	-	-	Soil improvers produced by recycled organic waste	Product does not contain peat; restriction on the use of minerals coming from protected areas.	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	Mattresses	9/07/2009	-	Packaging made by recyclable materials; plastic packaging shall be marked	-	-	Limitation of the concentration of various substances (e.g. Sb < 0.5ppm; Cu < 2 ppm)	-	Lifetime of the mattresses (calculated according to EN standard)
	Copying and graphic paper	7/6/2011	-	Information to promote recycling of paper	-	The use of recycled paper accounted in the calculation of energy use; - Information on the recycled content of paper to be provided	Restriction of use of certain woods	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-
	Tissue paper	9/7/2009	-	-	-	The use of recycled paper accounted in the calculation of energy use; - Information on the recycled content of paper to be provided	Restriction of use of certain woods	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-

Table 20 Ecodesign requirements in draft Ecolabel criteria for ERP and non-ERP

Product group	Date	Draft criteria about						
		Reusability	**Recyclability**	**Recoverability**	**Recycled content**	**Use of priority resources**	**Use of hazardous substances**	**Durability**
Imaging equipment	draft criteria (June 2012)	The manufacturer shall demonstrate that the imaging device can be easily dismantled […] for repairs and replacements of worn-out parts, upgrading older or obsolete parts, and separating parts and materials, ultimately for recycling or reuse. The applicant shall complete the "checklist for recyclable design"; The products must accept remanufactured toner and/or ink cartridges; The applicant shall offer a take-back system for the return of toner/ink modules and toner/ink containers			Plastic parts larger than 25g shall have in total a recycled and/or reused content of not less than 10 % by mass. The total post-consumer recycled content and the reused content of the external plastic parts shall be declared	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	The applicant shall ensure guarantee for repair or replacement of minimum five years; availability of spare parts
					cardboard packaging at least 80 % recycled material	-	Restricted use of mercury in lamps.	
Water tap	draft criteria (May 2012)	-	Packaging shall be easy to separate and recyclable	-	cardboard packaging at least 80 % recycled material	-	criteria on Ni-Cr coating	Reparability and availability of spare parts; warranty for 5 years
toilets and urinals	draft criteria (May 2012)	-	Plastic materials shall be marked correctly to ensure they are recovered, recycled or disposed of in the correct manner during the end-of-life phase.		-	-	-	Reparability and availability of spare parts; warranty for 5 years
Central Heating system	draft criteria (November 2011)	Promotion of reuse, recycling and generally sound end-of-life management (draft)			-	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	Product quality/usability and lifetime extension (draft)
Office Building	draft criteria (April 2012)	At least 80% in weight of the waste generated at the construction phase and the end of the service life of the building shall be prepared for being re-used, recycling and other material recovery, including backfilling operations. A waste management plan shall be developed by the constructor, applied during the construction phase and proposed for the demolition phase.			At least 50% in cost of the construction components installed in the building will be formed by products and materials containing at least 30% of recycled, reused and /or recovered materials	Use of low impacts construction materials and restriction in the use of some materials (e.g. wood)	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	The building shall be supplied with relevant user information for maintenance
Newsprints	final draft criteria (2012)	-	-	-	At least the 70 % (w/w) on the total amount of fibbers used for newsprint paper shall be recovered fibres.	-	Criteria based on lists of restricted substances (including some regulated ones), and/or restriction of use of substances with some risk phrases.	-

3.2.2 Ecodesign requirements in the scientific literature

An extensive review of Design for Recovery guidelines has been carried out by the University of Grenoble, within the framework of the industrial project EcoDEEE involving a consortium of electr(on)ic equipment manufacturers [EcoDEEE, 2008]. A list of various "Design for End-of-life Recovery" guidelines was identified based on literature analysis, experiences by manufacturers and information collected from the recovery industry. The guidelines were characterized according to various criteria (including e.g. applicability to product groups, applicability to specific components, type of recovery scenario considered) so that they can be easily be searched and identified by designers [Lacoste et al., 2011; Grenoble, 2012].

These guidelines are also relevant to identify possible new typologies of requirements for product policies. A short summary of the guidelines, updated with some new references, is shown in Table 21.

It is important to note that these guidelines are often generic and not related to quantified thresholds. In some cases the guidelines are derived from short sentences from the literature. Therefore these have to be considered as potential 'strategies' for ecodesign more than effective ecodesign requirements ready to be implemented. They can however be a source of inspiration for possible requirements.

In the next paragraphs some additional description is provided concerning two important strategies for ecodesign: dematerialization and design for disassembly.

Table 21 Guidelines for Design for Recovery of products (adapted and updated from [EcoDEEE, 2008])

Typologies of criteria for the ecodesign of products	References
Design for material recycling and part reuse	
Use materials with higher recyclability	[Dowie, 1995; Mathieux, 2002; Mathieux et al, 2008; Dewulf et al. 2001; TU Wien, 2008; EcoDEEE 2008]
For large polymer parts that are addressed to manual dismantling before recycling, and if a cooperation with recycler is set-up, choose among: ABS, HIPS, PP, P/E, PP+EPDM, PP-GF, PC, ABS-PC, PA, PA-6, HDPE, SAN. Otherwise prefer: PP, P/E, PP-GF, PP-EPDM; HIPS; ABS.	[Mathieux, 2002; Mathieux et al., 2008]
Avoid sticks and metal inserts on plastic parts	[Dowie, 1995; EcoDEEE 2008]
Minimise number of different types of materials (including additives for polymers and alloys for metals) mark plastic and metal parts according to ISO standards	[Dowie, 1995; Graedel, 1996; Johansson, 1997; Froelich et al., 2007]
Think of re-use of parts	[Zwolinski et al., 2006]
Avoid coating (e.g. painting, varnish) on metallic parts	[EcoDEEE, 2008]
Avoid coating (metal, plastic film, painting, textile, film, etc.) on plastics parts	[Graedel, 1996]
Recycled content	
Use recycled materials	[Dowie, 1995; ENSAM, 2002]
Separability of components	
If different types of polymers have to be closely associated, prefer types of plastics that could be easy separated after shredding	[Renault, 1994]
For materials that are not separable, prefer types of polymers or of metals that are compatible	[Renault, 1994; Castro et al., 2005; Froelich et al., 2007]
Design for disassembly	
Minimise number of fasteners Think of fasteners that can be broken instead of dismantled Minimise number of parts	[Dowie, 1995; Johansson, 1997]
Design metallic parts and assemblies so that the liberation of pure material particles during shredding is facilitated	[Froelich, 2007; Castro et al., 2005]
Prefer fasteners easy to remove	[Dowie, 1995; Graedel, 1996]
Make sure that fasteners that will have to be unlocked are easy accessible / visible	[Haoues et al., 2007; Dowie, 1995]
Focus on a limited number of parts whose characteristics (mass, material, position, etc.) bring good recyclability performances	[Renault, 2001]
Electronic components and other critical parts should be put in the same location.	[EcoDEEE, 2008]
Make design modular	[Dowie, 1995; Graedel, 1996; Johansson, 1997]
Make high value parts easy accessible	[Dowie, 1995; Johansson, 1997]
Think of Active Disassembly techniques (fasteners activated by external triggers)	[Duflou et al, 2006, Chiodo et al, 1998 ; Hislop et Hill, 2011]
Marking of parts for sorting (e.g. labels, marking, colour, smart barcodes, tracers, magnetic dust, etc.)	[EcoDEEE, 2008; Bezati et al., 2011; Hislop et Hill, 2011]
Pollutants	
Reduce the number / the weight of pollutants	[Graedel, 1996]
Make pollutant (battery, fluids, some PCB, etc.) easy accessible and clearly marked	[Dowie, 1995, Graedel, 1996; Johansson, 1997; Eco'DEEE 2008]
Durability	
Promote longer life for products (through product quality, reparability, etc.) especially for products with most significant impact out of use phase	[Lagerstedt et Luttrop, 2006]
Think of reparability of product	[Zwolinski, 2006; TU Wien, 2008; Lagerstedt et Luttrop, 2006]
Think of over dimensioning some parts so that it is possible to machine them during remanufacturing process.	[TU Wien, 2008]
Information	
Think of filling-in a "recycling profile" (or end-of-life treatment manual) for the product to be communicated to treatment facilities	[Rose, 2000; Mathieux et al, 2001; Dewulf, 2001; EU, 2012; TU Wien 2008]
Dematerialisation	
Minimise weight of the product	[EcoDEEE, 2008]

3.2.2.1 Dematerialization

A special attention is here focused to the dematerialization as a possible strategy for the improvement of resource efficiency. Dematerialization is defined by UNEP as "*the reduction of the total material and energy throughput of any product or service, and thus the limitation of its environmental impact. This includes reduction of raw materials at the production stage, of energy and material inputs at the use stage, and of wastes at the disposal stage*" [UNEP, 2001]. Furthermore UNEP identifies as possible of "the material intensity of products and services, i.e. by increasing material efficiency, and especially reducing the use of primary material resources" [UNEP, 2011]. Dematerialization strategies can be translated into:

- the conception and manufacturing of a smaller and/or lighter product
- the replacement of material goods by non-material substitutes (e.g. by the use of electronic formats)
- the reduction in the use of material systems or of systems requiring large infrastructures (e.g. substituting products by services)

Dematerialization strategies are often referred to in voluntary initiatives by manufacturing companies. Dematerialization has been already parts of product's design *being* it related to the reduction of the use of inputs and the reduction of associated costs. For example some Ecodesign guidelines suggest the designer to check if "measures have been realized to optimize the product for strength and the required wear resistance and to minimize material input by a solution balancing strain and strength" [TU Wien, 2008]. In some cases authors estimated that "for most product we could use one third less of metals without seeing a loss of performance" [Allwood et al., 2011].

However, dematerialisation can also have adverse effects. For example it was noticed that "less valuable elements in complex products will adversely affect profitability" and therefore "dematerialization will negatively impact recycling viability, simply said, if there is not enough gold in the system to drive it" [UNEP, 2011b].

One of the main problems of dematerialisation is currently its accounting and translation into effective policies and actions [te Riele et al., 2001]. On such purpose, it has been observed that on various environmental labelling schemes checked, the only criterion found on dematerialization was limited to the "Declaration of product weight" by manufacturer [IEE1680.1, 2009].

Further research on the topic is needed including the need to develop and test metrics and indicators for dematerialization. This can be done in particular looking at specific products.

3.2.2.2 Design for disassembly

Also interesting is the development of technologies for the improvement of product disassemblability. For example research is currently focusing on automated sorting of plastic wastes. Sorting of plastic can be divided into two categories [Bezati, et al., 2011]:

- Microsorting. It is related to the sorting of small pieces of shredded plastics. Density separation and flotation are generally used but these processes are slow and do not provide polymers of high purity. The electric/electrostatic separation can be used for plastics of significantly different dielectric constant, but this technique requires dry and clean plastic surfaces.

- Macrosorting. It is related to the sorting of larger plastic parts. "*An optical sorting is limited for colour separation of plastics only; the near infra-red is unsuitable for dark objects whereas middle infra-red can identify them but cannot provide a high-speed identification. The X-ray technology, transmission or fluorescence, is limited to the separation of PVC from PET and the laser induced breakdown spectroscopy is unsuitable for high speed automatic sorting*". This kind of sorting needs preliminary disassembly of plastic parts.

Moreover, all the sorting techniques mentioned above could not identify different grades of the same polymer. New technologies are currently under development including magnetic systems (based on the dispersion of magnetic compounds in the material) and the use of X-ray fluorescence spectrometry, which can potentially detect a tracer system dispersed into dark polymer materials [Bezati et al., 2011]. Among the possible tracing substances, rare earth substances seem to be one of the most suitable [Bezati et al., 2011].

Once different polymers are identified, automatic systems should be developed to separate the fraction. These systems could be based, for example, on pressurized air flows that separate the material, by electrostatic separators or by some other innovative systems. However, these systems are still at an early stage of development and these are in several cases proprietary technologies with limited disclosure of information.

Other options to improve the disassemblability and/or removal of plastics include, for example, the adoption of 'active disassembly' fasteners that employ 'shape memory' materials. For example, when heat is applied, polymers revert from a screw thread to a smooth tube, enabling automated dismantling (examples of application of automatic disassembly on computers is presented by Torres et al., 2009). Automatic disassembly could be developed in future by determining the optimal disassembly sequence [Lambert, 2002] It is currently under discussion also the use of 'smart barcodes' so that components can be easily identified and separated [Hislop et Hill, 2011]. However, even in this case, their use in economically viable plants is still at an early stage of development.

3.2.3 Summary of potential typologies of ecodesign requirements

The previous sections illustrated some examples of ecodesign requirements in environmental labelling schemes and in the scientific literature.

In particular various requirements concerning Reusability/Recyclability/Recoverability (RRR) have been observed. However criteria about these parameters are sometimes based on general statements (e.g. in the Ecolabel for furniture stating that "the product must be easily recyclable") or based on methods to be defined by the manufacturers (as e.g. in the draft EU Ecolabel criteria for buildings). For this reason it is here concluded that the definition of requirements on RRR should be related to specific methods (as those developed by the current project – Report n° 3). Therefore, examples of potential RRR requirements could be based on declaration and/or thresholds of RRR and RRR benefits rates[53].

Concerning the durability, the method developed in Report n° 3 allows to assess if and to what extent it is worth to prolong the useful life of a given product. Once it is estimated that this convenience occurs and it is also relevant in the product life-cycle balances, some potential product requirements

[53] These typologies of requirements have been also discussed by the project 'EP1 – Report n° 2 – Chapter 7' [JRC, 2011].

could be enforced to potentially underpin the extension of the product useful life. According to the previous analysis, these requirements can include, for example:

- The identification of key components for durability. These are the product's parts that are largely subjected to worn out and/or breakage and whose functionality would affect the product's useful life. Information about the key parts should be provided by manufacturers.
- The accessibility of key parts for their non-destructive disassembly for replacing.
- The provision and availability of spare parts, for a sufficient time after the product selling.
- The extended warranty for the products or for some key components.

Afterwards, possible 'typologies' of criteria have been derived from the previous analysis, grouping homogeneous product's requirements together, based on expert judgement. The 'typologies' of ecodesign criteria obtained are illustrated in Table 22.

Table 22 Typologies of ecodesign requirements

Typology of Ecodesign requirement		Parameter potentially influenced by the requirement:				
Typology	Sub-typology	RRR	Use of priority resources	Recycled content	Use of haz. Subst.	Durability
Declaration of indices (RRR rates, , RRR benefits rates, Recycled content, Recycled content benefit)	General indices	X	X	X		
	Indices restricted to some specific material (e.g. RRR rates or Recycled content restricted to plastics, CRM, etc.)	X	X	X		
Threshold of indices (RRR rates, RRR benefits rates, Recycled content, Recycled content benefit)	General indices	X	X	X		
	Indices restricted to some specific material (e.g. RRR rates or Recycled content restricted to plastics, CRM, etc.)	X	X	X		
Design for recycling	Use of compatible materials (or forbid the jointly use of materials that are not compatible for recycling)	X				
	Use of materials more recyclable	X	X			
	Reduce number of contaminants (labels, glue, solders, etc.)	X				X
Design for disassemblability / dismantlability	Time based index (e.g. dismantling of a component)	X	X	X	X	
	Mass / Time based index	X	X	X	X	
	Non destructive disassembly (for repair/substitution)					X
	Reduction / simplification of fastening (e.g. reduction of number and typologies)	X	X		X	X
Availability of spare parts						X
Warranty						X
Indices for durability	According to standardized measurement of performances (when available)					X
Dematerialization	Reduction of the weight of materials	X	X			X
	Design of components for optimal use of materials	X	X			X
Declaration of substances	BOM of product or parts (at different level of detail)	X	X		X	
	Relevant substances (e.g. CRM to be recycled)	X	X		X	
	Pollutants (e.g. flame retardants), which interfere with EoL treatments	X	X		X	
Threshold of substances	Relevant substances (e.g. CRM to be recycled)	X	X		X	
	Pollutants (e.g. flame retardants), which interfere with EoL treatments	X	X		X	
Marking / labelling / tracing	Easy identification of recyclable materials / parts	X	X	X	X	
	Identification of pollutants	X	X	X	X	
	Use of innovative technologies for the automatic sorting systems (tracing substances, magnetic powders, etc.)	X	X		X	
Provision of information		X	X	X	X	X

3.3 Costs/benefits associated to ecodesign requirements

Costs of design

Due to the small number of companies engaged in ecodesign, it has been recently observed that no large-scale study is available on the economic benefits and costs of ecodesign [Plouffe et al., 2011].

It is commonly acknowledged that the costs associated to the design phase of the product represent a limited share (less than 5%) of the life-cycle costs of an industrial product [Salomone, 1995]. Some more recent studies have been performed about the costs of design in the building sectors, estimated to be lower than 1% of the life-cycle costs [Griffis and Kwan, 2008] or around 2.5% of production costs [Liang et al., 2007].

Although no robust figures on costs of design are available, it can be assumed that also the costs for design of ErP represents a small fraction of the overall life-cycle costs.

Costs associated to identified requirements

The potential typologies of requirements (illustrated in Table 22) can be sub-divided into three categories due the efforts required by the manufacturers for their implementation:

- **Category A**. Requirement implying very low efforts to be implemented: this is the case of declarative/information requirements of indices or of the composition or content of some parts and substances. Efforts are mainly due to the acquisition of some data from design teams and suppliers, being the majority of the requested data are already possessed by the manufacturer or their supply chains.
- **Category B.** Requirement implying minor to medium efforts to be implemented: this is the case of requirements that imply the redesign of some product's components including for example: the improvement of disassemblability, the selection of more recyclable materials, the reduction of source of contamination (e.g. glue, soldering, and labels), the marking of some components, and the availability of spare parts or additional warranties. It is highlighted that the majority of such requirements can be easily integrated at the design stage since they are good design practices that are (or at least should be) already addressed by design/production teams. Moreover, design requirements on better dismantlability could also bring reduction of costs for the assembly and the maintenance phases [Boothroyd et Alting, 1992]. To give an idea of reduction potentialities, it is often estimated that assembly time can be cut by 60% thanks to Design for Assembly techniques [DFMA, 2012] hence contributing to major costs reduction in the product life cycle costs.
- **Category C.** Requirement implying medium more significant efforts to be implemented: this is the case of threshold requirements or dematerialization. These requirements in fact might imply major re-design processes of the product or of some of its key components, in order to achieve the thresholds.

Based on the expert judgments, the following Table 23 subdivides the previously identified typology of requirements according to the above mentioned categories.

Other potential benefits of the environmentally conscious design

On the other hands, various studies underlined potential economic benefits of implementing voluntary ecodesign measures for manufacturers, which can be subdivided into three typologies [Plouffe et al., 2011]:

- Cost reductions: it can be achieved in various ways such as: the use of recycled materials, which can cost less, better/less use of raw materials, improved logistics and energy savings.
- Increased revenues: eco-designed products provide greater satisfaction to consumers, who are increasingly sensitive to environmental issues. At the same time, some eco-designed products can generate economic benefits for the buyers, such as lower energy consumption, and can therefore contribute to their loyalty to the manufacturing company.
- Non-economic benefits for the organization: Ecodesign allows the firm to play a proactive role with respect to regulations; Ecodesign can enhance the firm's image and improve relationships with various stakeholders: financial, environmental groups, neighbouring communities, and so on.

Additional benefits for innovative industry

It is also further considered that some ecodesign requirements can induce future benefits in the promotion of innovation. This is, for example, the case of declaration of the amount and/or the location of some relevant substance (e.g. CRM) in the product, which can contribute to the improvement or development of recycling technologies of these substances.

On the other hands the technological evolution can contribute to the reduction of EoL costs. The costs of component disassembly / materials sorting represent a relevant part of costs of recycling. Although no precise figure is available, it is assumed that automatic sorting / disassembly based on innovative technologies (including e.g. tracers, barcode and active disassembly, automatic disassembly previously discussed) could contribute to reduce costs and increase efficiency of recycling treatments. This would hence drive the European recycling industry towards innovations and to development. The European manufacturing industry would also be driven towards product innovations adapted to recycling process innovations. A qualitative assessment of potential costs/benefits of various types of products' requirements is presented in Table 23.

Table 23 Potential costs/benefits related to the application of the typologies of products' requirements

Typology of ecodesign requirement	Estimated cost category
Declaration of indices	A
Threshold of indices	B/C
Design for recycling	B
Design for disassemblability / dismantlability	B
Availability of spare parts	A / B
Warranty	A / B
Indices for durability	A
Dematerialization	(*)
Declaration of substances	B
Threshold of substances	C
Marking / labelling / tracing	A / B

Legend:
A. low costs/efforts
B. Minor to medium costs/efforts
C. Medium to high costs/efforts
(*) difficult to be estimated

3.4 Conclusions

The present chapter illustrated potential ecodesign requirements focusing on the project's parameters (RRR, use of relevant resources, recycled content, use of hazardous substances and durability). Potential requirements have been identified from environmental labelling systems and publication in the scientific literature.

The outcome of the Chapter is a list of typologies of potential ecodesign requirements. This list aimed at grouping criteria more or less homogeneous among them, based on expert judgements. Such typologies have been afterwards analyzed to qualitatively estimate potential costs and benefits related to their application.

The typologies of ecodesign requirements will be used as an input for a method for the identification and assessment of relevant ecodesign requirements at the case-study level and at the product group level. This method will be illustrated in the following Chapter 4.

4. Identification of potentially relevant ecodesign requirements

4.1 Overview of the project's methods and identification of potentially relevant ecodesign requirements

The previous chapter illustrated main characteristic of some typologies of ecodesign requirements, including potential benefits and costs. Report n° 3 introduced the developed methods for the assessment of project's parameters (RRR, Recycled content, use of relevant resources, use of hazardous resources, durability).

The present section discusses a method to combine these two elements (methods and requirements) for the identification and assessment of potentially relevant requirements related to a case-study product.

The method is based on the following steps (Figure 5):

1. *Selection and characterization of the product*. This step includes the selection of the product group and the analysis of some representative case-study products. Afterwards, information about the product(s) (BoM, disassembly) and life-cycle impacts of the product(s) are collected/calculated.
2. *Application of the methods*. This is further subdivided in:

   2.1 *Definition of EoL scenario(s)*. EoL scenario(s) of the product are defined, representative of the current EoL treatments in the EU for the selected product group. This step can also include a 'dynamic' analysis of potential future EoL scenario(s): this analysis is particularly relevant when significant variations of the EoL scenario are foreseen in the short/medium term.

   2.2. *Calculations and assessment*. This step includes the running of the project's methods (see Report n° 3). The outcomes of the analysis are the calculation of the various indices[54] and results of the assessment of the durability and of the use hazardous substances)
3. *Identification of product's resources efficiency 'hot spots'*. 'Hot spots' include key components and/or product parameters that are relevant in terms of relevant life-cycle impacts and/or environmental improvement potentials. This step is further subdivided in:

   3.1 *Identification of key components* (for hazardous substance and durability). The methods are applied to identify product's parts that are relevant for their content of hazardous substances and for the durability of the product.

[54] Indices are: RRR rates, RRR benefit rate, Recycled content index, Recycled content benefit index, and Durability index. See Report n° 3 for further details.

3.2. *Identification of losses for RRR indices*. 'Losses' occur when product's parts can grant high environmental benefits at EoL (if reused/recycled/recovered) but this potential is only partially exploited due to the current EoL treatments. This could be translated in formula as:

Formula 2. Losses = $RRR_{Benchmark} - RRR_{Base\text{-}case}$

Where:

- Losses = environmental benefit (calculated for certain impact categories) that is lost because product is not optimized for the EoL treatments
- $RRR_{Benchmark}$ = Indices[55] calculated for a potential benchmark[56] product
- $RRR_{Base\text{-}case}$ = Indices[57] calculated for the selected case-study product(s)

3.3. *Identification of hot spots*. Results of the previous steps (*3.1* and *3.2*) identified key components for some of the considered parameters. This new step combines these results to identify 'hot spots' at the product level.

4. *Identification of potentially relevant requirements at the product level*. Once hot spots have been identified, it is performed an analysis to identify potential ecodesign requirements that could contribute to the improvement of the product performances (e.g. contributing to the reduction of the losses or to the increase of durability). A list of typologies of requirements (as in Table 22) can contribute to this objective. Requirements are therefore tested to assess if and how they can produce, at the case-study product level, relevant life-cycle benefits.

5. *Assessment of requirements at the 'product group' level.* The last step consists in the extension of the analysis from the 'case-study product' level to the whole 'product group' level. Performances of different products (representative of the considered product category) are assessed over the considered present and future EoL scenario(s). Environmental benefits at the product level due to the selected requirements are afterwards multiplied by the flows of different product within the considered economy. Results are then normalized[58] to assess their significance.

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[55] The acronym RRR is here used to refer to RRR rates, RRR benefit rates, Recycled content index and Recycled content benefit index.

[56] It is assumed that the 'benchmark product' is a product specifically designed to have high values of the RRR indices.

[57] The acronym RRR is here used to refer to RRR rates, RRR benefit rates, Recycled content index and Recycled content benefit index.

[58] Normalization can be applied referring to different values as: the impacts of the whole product group (e.g. the washing machine product group), and/or the impacts of an economic macro-sector (e.g. impacts of ErP), and/or impacts of a geographic area (e.g. impact at the EU level).

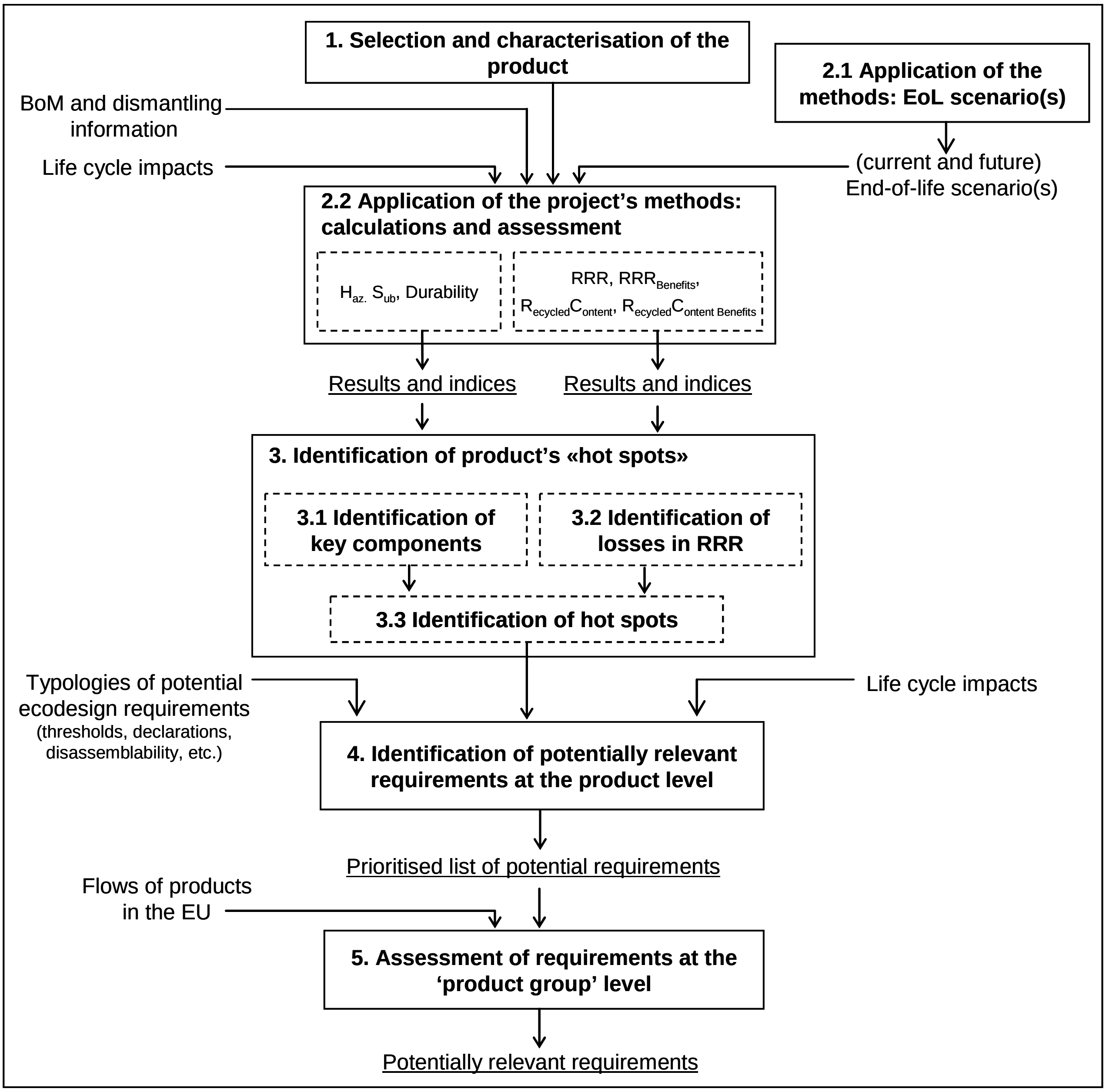

Figure 5. Overview of the project's methods and their application for the identification of potentially relevant ecodesign requirements

4.2 Conclusions

A method for the identification of potential relevant requirements has been introduced. The method combines the application of the project's methods (Report n° 3) to a product group first to identify 'hot spots' (key components and/or product parameters that are relevant in terms of relevant life-cycle impacts and/or improvement potential) and, afterwards to assess, among the typologies of requirements previously defined, those that could produce relevant environmental benefits (both at the case-study product level and at the product group level).

The method will be applied in the following chapters to the selected case-study products.

5. Case-study: ‘imaging equipment

5.1 Introduction

The case-study selection task identified the “imaging equipment” product as one of the most suitable for relevant ecodesign requirements on resource efficiency. In particular, the large amount of plastics components suggests the suitability for recycled content requirements.

The following sections will illustrate an environmental analysis of an exemplary product belonging to that category. It is underlined that the case-study follows a simplified approach. In fact the analysis has been based upon data provided by the preparatory study already developed in the context of Ecodesign Directive, and it will be limited to the estimation of the impacts related to the use of primary and secondary plastics.

5.2 “Imaging equipment” product group

A preparatory study has been published in 2007 concerning the “Imaging Equipment” [Fraunhofer IZM, 2007].

This product category is very broad and boundaries and functions are generally not well defined. As notice by authors of the preparatory study, the “imaging equipment” category is not homogeneously defined “even under the given specification of functionality (print, copy, scan, and facsimile)”.

The functions general accomplished by imaging equipment are:

- Printing
- Copying
- Scanning
- Facsimile transmission

Furthermore, imaging equipment involves a variety of technologies as well as performance and application criteria which determine the environmental impact of a particular product.

Following the classification from EU statistics, some sub-categories among imaging equipment are identified. These include:

- “*office imaging equipment*”; printer, copier, flatbed scanner, and facsimile machines that are used by costumers in private homes or in an office environment.
- “*production imaging equipment*”. These are based on the same digital imaging technology like office equipment however the particular functionality, use patterns, the quantity and quality (e.g. colour quality, large format, hardcopy material) of created images are different.

- “*special media imaging equipment*”. Including a wide spectrum of products mostly in medical, industrial, and military applications (e.g. X-ray diagnostic systems, fields, thermal imaging equipment)
- “*integrated secondary imaging modules*”, which comprise products with an integrated printing functionality such as cash registers or automatic teller machines.

Among these, the “office imaging equipment” is the most economically significant product category with high annual unit sales. The category includes commercially available products, which were designed for the main purpose of producing a printed image (paper document or photo) from a digital image (provided by a network/card interface) through a marking process, for both consumers and business purposes.

The definition of office imaging equipment also covers multifunction devices (MFD) which incorporate a printing function in combination with a scanning/copying function and/or facsimile function.

The preparatory study also estimates the volumes of equipment sold in the past year, and the future forecast for the future. Finally, stocks of office imaging equipment are estimated for the years 2005, 2010 and 2020 (Figure 6).

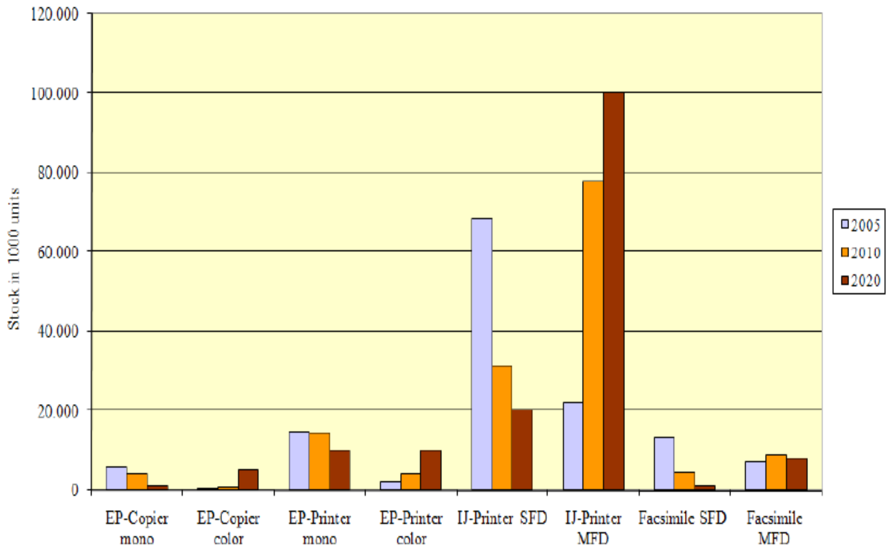

Figure 6. Variations of the stocks of office imaging equipment[59] [Fraunhofer IZM, 2007]

The main conclusion of the analysis of the market trends are that:

- Electro Photography (EP)
  - 17% market share of EP printers and copiers, but 85% of total image output
  - usually higher imaging speed (volume technology)
  - power consumption by fusing (thermal image fixing process)
- Ink-Jet (IJ)
  - 65% market share of Inkjet printers, but only 10% of total image output

[59] Electro-photography (EP) copiers and printers (monochromatic and colour); Ink jet (IJ) devices and facsimiles with Single Functional Device –SFD – or Multi Functional devices – MFD.

- usually lower imaging speed (value technology)

Furthermore, it is observed a miniaturization and digitalization that leads towards multi functional devices (MFD):

- Single Function Devices (SFD)
  - Printers are the dominant SFD, followed by scanner and fax
  - SFD market shares is declining
- Multi Function Devices (MFD)
  - MFD become mainstream due to better performance to price ratio
  - most Copiers are already MFD
  - printer-, copier- and fax-based MFDs will overtake SFDs in volume of sales

The next steps of the analysis will focus on the Ink Jet Multi Function Device (IJ-MFD), that in the preparatory study as been identified as one of the products with the largest relevance in the next decade (see Figure 6).

5.3 Selection of an exemplary product

The preparatory study performed a technical analysis of IJ-Printer/MFD based on four products from different manufacturers [Fraunhofer IZM, 2007].

The four products show differences in their functional spectrum and performance. These differences relate to the applied technologies and components. All the considered four products have integrated flatbed scanner incorporating CCD (Charge Coupled Device) or CIS (Contact Image Sensor) as sensor and with CCFL (Cold Cathode Fluorescent Lamp) and/or LED (Light Emitting Diode) arrays as light source. Because the large variety of the products and because their different uses in a personal (home) and workgroup (office) environment, the preparatory study defined an average product as "base-case". Bill of material of the "base-case" is shown in Table 24.

It is noted that for the average base-case plastics components represent about 53% of the whole products. According to the preparatory study, [Fraunhofer IZM, 2007] several different plastics are utilized, but three plastics are more relevant: high impact polystyrene 'HI-PS' (25% in mass); Acrylonitrile Butadiene Styrene 'ABS' (11%) and polystyrene 'PS' (8.2%). These plastics are used for housing and other functional components. The presence of plastics into the product's BOM in such large percentages (more than half of the product) makes this product base case as potentially relevant for requirements on the use of recycled plastics.

Table 24 Bill of Materials for the base-case of the Ink Jet printer – multi functional device (IJ-MFD) [Fraunhofer IZM, 2007]

Version 5 VHK for European Commission 28 Nov. 2005 — Document subject to a legal notice (see below)

ECO-DESIGN OF ENERGY-USING PRODUCTS — EuP EcoReport: INPUTS — Assessment of Environmental Impact

Nr	Product name	Date	Author
	Base Case V5_IJ-MFD-Personal		

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1		97,1	1-BlkPlastics	1-LDPE
2		40,8	1-BlkPlastics	2-HDPE
3		76,2	1-BlkPlastics	4-PP
4		767,6	1-BlkPlastics	5-PS
5		51,0	1-BlkPlastics	6-EPS
6		2334,5	1-BlkPlastics	7-HI-PS
7		41,2	1-BlkPlastics	8-PVC
8		2,7	1-BlkPlastics	9-SAN
9		1041,7	1-BlkPlastics	10-ABS
10		211,8	2-TecPlastics	11-PA 6
11		84,9	2-TecPlastics	12-PC
12		16,6	2-TecPlastics	13-PMMA
13		5,9	2-TecPlastics	14-Epoxy
14		37,8	2-TecPlastics	15-Rigid PUR
15		116,3	2-TecPlastics	16-Flex PUR
16		15,7	2-TecPlastics	18-E-glass fibre
17		0,0	2-TecPlastics	19-Aramid fibre
18		1863,1	3-Ferro	21-St sheet galv.
19		38,1	3-Ferro	24-Ferrite
20		27,4	3-Ferro	25-Stainless 18/8 coil
21		67,2	4-Non-ferro	26-Al sheet/extrusion
22		36,0	4-Non-ferro	28-Cu winding wire
23		145,5	4-Non-ferro	29-Cu wire
24		44,0	4-Non-ferro	30-Cu tube/sheet
25		0,7	4-Non-ferro	31-CuZn38 cast
26		0,0	5-Coating	40-Cu/Ni/Cr plating
27		0,2	5-Coating	41-Au/Pt/Pd
28		74,3	6-Electronics	42-LCD per m2 scrn
29		90,5	6-Electronics	44-big caps & coils
30		28,2	6-Electronics	45-slots / ext. ports
31		2,7	6-Electronics	46-IC's avg., 5% Si, Au
32		4,2	6-Electronics	47-IC's avg., 1% Si
33		13,8	6-Electronics	48-SMD/ LED's avg.
34		107,4	6-Electronics	49-PWB 1/2 lay 3.75kg/m2
35		29,3	6-Electronics	50-PWB 6 lay 4.5 kg/m2
36		7,2	6-Electronics	51-PWB 6 lay 2 kg/m2
37		5,1	6-Electronics	52-Solder SnAg4Cu0.5
38		650,2	7-Misc.	54-Glass for lamps
39		901,0	7-Misc.	56-Cardboard
40		161,1	7-Misc.	57-Office paper
41		115,8	6-Electronics	98-controller board
	TOTAL	9355		

5.4 Environmental analysis of the exemplary product

The environmental analysis of the exemplary product has been performed with the updated version of the Methodology for the Ecodesign of Energy-related Products 'MEErP' ecoreport tool [VHK, 2011].

The input page has been compiled as following:

- Inputs of the "MATERIALS Extraction & Production" have been compiled according to data of Table 24.

- Inputs of the "manufacturing" and "distribution" phase have been set to default values (Table 25);
- Inputs concerning the "*Use phase–direct impact*" have been compiled according to the assumption of the preparatory study[60] [Fraunhofer IZM, 2007]. In particular the two scenarios of "low utilization" and "moderate use" have been reproduced, with an electricity consumption of respectively 18.28 kWh/year and 21.99 kWh/year, and 4 years of useful life. Impacts due to paper and ink consumption during the use phase have been not considered[61]. Indirect energy consumption has been not considered. A summary of the inputs is illustrated in Table 26 and Table 27.
- Inputs concerning the "*Disposal and recycling*" section are set to default values except for the reuse percentages (assumed to be null), and disposal of plastics (assumed 50% landfilled and 50% incinerated. Summary of inputs in Table 28.

Table 25 Inputs concerning the manufacturing and distribution phase for the analysis of the Ink Jet printer – multi functional device (IJ-MFD)

Pos nr	MANUFACTURING Description	Weight in g	Percentage Adjust	Category index (fixed)
201	OEM Plastics Manufacturing (fixed)	4942		21
202	Foundries Fe/Cu/Zn (fixed)	0		35
203	Foundries Al/Mg (fixed)	0		36
204	Sheetmetal Manufacturing (fixed)	0		37
205	PWB Manufacturing (fixed)	478		54
206	Other materials (Manufacturing already included)	3935		
207	Sheetmetal Scrap (Please adjust percentage only)	0	25%	38

Pos nr	DISTRIBUTION (incl. Final Assembly) Description		Answer	Category index (fixed)
208	Is it an ICT or Consumer Electronics product <15 kg ?		NO	60
209	Is it an installed appliance (e.g. boiler)?		NO	61
				63
210	Volume of packaged final product in m^3	in m3	0.029	64
				65

60 Scenarios "V5" (low utilization) and "V6" (moderate use) of the preparatory study for imaging equipment [Fraunhofer IZM, 2007].

61 According to the preparatory study on imaging equipment, impacts due to ink have been not considered because not included in the database of the Ecoreport. The use of the paper is, instead, not included in the analysis because it does not depend on a single imaging equipment design (see [Fraunhofer IZM, 2007] Task 5 report- section 5.2.1.2 and following).

Table 26 Use phase for the ink jet MFD in the "low utilization" scenario

Scenario A "low utilization"

Pos nr	USE PHASE direct ErP impact Description		unit	Subtotals
226	ErP Product (service) Life in years	4	years	
	Electricity			
227	On-mode: Consumption per hour, cycle, setting, etc.	18.28	kWh	18.28
228	On-mode: No. of hours, cycles, settings, etc. / year	1	#	
229	Standby-mode: Consumption per hour	0	kWh	0
230	Standby-mode: No. of hours / year	0	#	
231	Off-mode: Consumption per hour	0	kWh	0
232	Off-mode: No. of hours / year	0	#	
	TOTAL over ErP Product Life	0.07	MWh (=000 kWh)	66
	Heat			
233	Avg. Heat Power Output	0	kW	
234	No. of hours / year	0	hrs.	
235	Type and efficiency (Click & select)			86-not applicable
	TOTAL over ErP Product Life	0.00	GJ	
	Consumables (excl. spare parts)			material
236	Water	0	m^3/year	84-Water per m3
237	Auxilliary material 1 (Click & select)	0.0728	kg/ year	86 -None
238	Auxilliary material 2 (Click & select)	0	kg/ year	86-None
239	Auxilliary material 3 (Click & select)	0	kg/ year	86-None
240	Refrigerant refill (Click & select type, even if there is no re	0	kg/ year	3-R404a; HFC blend; 3920
	Maintenance, Repairs, Service			
241	No. of km over Product-Life	0	km / Product Life	87
242	Spare parts (fixed, 1% of product materials & manuf.)	94	g	1%

Table 27 Use phase for the ink jet MFD in the "moderate use" scenario

Scenario B "moderate use"

Pos nr	USE PHASE direct ErP impact Description		unit	Subtotals
226	ErP Product (service) Life in years	4	years	
	Electricity			
227	On-mode: Consumption per hour, cycle, setting, etc.	21.99	kWh	21.99
228	On-mode: No. of hours, cycles, settings, etc. / year	1	#	
229	Standby-mode: Consumption per hour	0	kWh	0
230	Standby-mode: No. of hours / year	0	#	
231	Off-mode: Consumption per hour	0	kWh	0
232	Off-mode: No. of hours / year	0	#	
	TOTAL over ErP Product Life	0.09	MWh (=000 kWh)	66
	Heat			
233	Avg. Heat Power Output	0	kW	
234	No. of hours / year	0	hrs.	
235	Type and efficiency (Click & select)			86-not applicable
	TOTAL over ErP Product Life	0.00	GJ	
	Consumables (excl. spare parts)			material
236	Water	0	m^3/year	84-Water per m3
237	Auxilliary material 1 (Click & select)	0.0728	kg/ year	86 -None
238	Auxilliary material 2 (Click & select)	0	kg/ year	86-None
239	Auxilliary material 3 (Click & select)	0	kg/ year	86-None
240	Refrigerant refill (Click & select type, even if there is no re	0	kg/ year	3-R404a; HFC blend; 3920
	Maintenance, Repairs, Service			
241	No. of km over Product-Life	0	km / Product Life	87
242	Spare parts (fixed, 1% of product materials & manuf.)	94	g	1%

Table 28 Summary of inputs for the disposal and recycling of the ink-jet printer

Pos nr	DISPOSAL & RECYCLING Description												AVG
263	EoL mass fraction to re-use, in %						0%					0%	0.0%
264	EoL mass fraction to (materials) recycling, in %	0%	0%		95%		50%	65%	30%	39%	60%	30%	36.8%
265	EoL mass fraction to (heat) recovery, in %	50%	50%		0%		0%	1%	0%	0%	0%	10%	26.1%
266	EoL mass fraction to non-recov. incineration, in %	0%	0%		0%		30%	5%	5%	5%	10%	10%	2.7%
267	EoL mass fraction to landfill/missing/fugitive, in %	50%	50%		5%		20%	29%	65%	56%	30%	46%	34.3%
268	TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99.9%
269	EoL recyclability****, (click& select: 'best', '>avg', 'avg' (basecase); '< avg'.; 'worst')	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	ovg
		01	01	01	01	01	01	01	01	01	01	01	

Table 29 Impact assessment of the ink-jet printer-MFD (base-case)

	Scenario A - Low Utilization				
	Production	**Distribution**	**Use**	**EoL**	**Total**
Total Energy – Global Energy Requirement (GER)	1,529	145	671	69	**2,414**
Water (process)	166	0	2	-43	**125**
Water (cooling)	1,024	0	39	293	**1,356**
Waste, non-haz./ landfill	5,294	124	385	-450	**5,352**
Waste, hazardous/ incinerated	314	2	14	-110	**220**
Greenhouse Gases in GWP100	77	11	29	49	**165**
Acidification, emissions	456	32	128	-73	**543**
Volatile Organic Compounds (VOC)	3	1	15	10	**28**
Persistent Organic Pollutants (POP)	54	1	3	-1	**56**
Heavy Metals	90	6	11	-32	**75**
PAHs	278	4	4	108	**394**
Particulate Matter (PM, dust)	135	100	4	-39	**200**
Heavy Metals (water)	88	0	4	-24	**67**
Eutrophication (water)	5	0	0	-1	**4**
	Scenario B - Moderate Use				
	Production	**Distribution**	**Use**	**EoL**	**Total**
Total Energy – Global Energy Requirement (GER)	1,529	145	804	69	**2,547**
Water (process)	166	0	2	-43	**125**
Water (cooling)	1,024	0	45	293	**1,362**
Waste, non-haz./ landfill	5,294	124	454	-450	**5,421**
Waste, hazardous/ incinerated	314	2	16	-110	**222**
Greenhouse Gases in GWP100	77	11	34	49	**171**
Acidification, emissions	456	32	153	-73	**568**
Volatile Organic Compounds (VOC)	3	1	18	10	**31**
Persistent Organic Pollutants (POP)	54	1	3	-1	**57**
Heavy Metals	90	6	13	-32	**77**
PAHs	278	4	5	108	**394**
Particulate Matter (PM, dust)	135	100	4	-39	**201**
Heavy Metals (water)	88	0	4	-24	**68**
Eutrophication (water)	5	0	0	-1	**4**

The results of the impact assessment by the Ecoreport tool are illustrated in Table 29 and Figure 7. Comparing these results with those obtained by the preparatory study [Fraunhofer IZM, 2007] it is possible to note similar outcomes, with manufacturing as most the relevant phase for the majority of the impact categories, followed by the use phase.

Impacts calculated by the preparatory study are however different especially concerning the use phase and the EoL. These differences are ascribed to the updates in the new Ecoreport 2011 concerning the inventory datasets for materials and energy and the different modelling of the disposal and recycling stage [VHK, 2011].

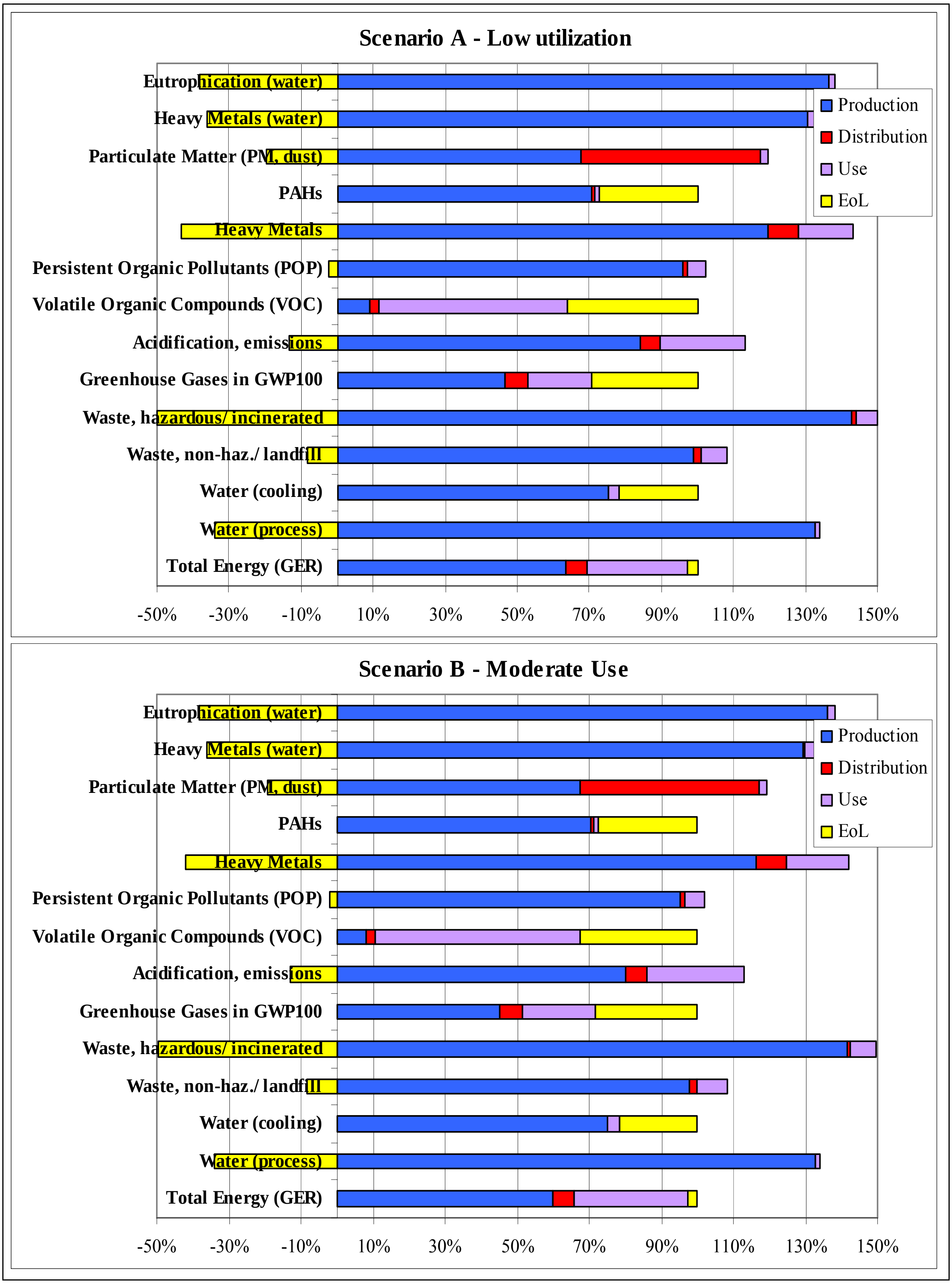

Figure 7. Life Cycle Impact Assessment for the Ink-Jet MFD

5.5 Analysis concerning the use of recycled plastics

The use of recycled plastics into "sounds and imaging equipment" has been already documented into other researches. For example a study from WRAP [WRAP, 2010] analyzed the use of recycled plastics into sound speakers. Sources of recycled plastics were: HI-PS from TV sets, HI-PS from a mixture of WEEE and other products; and the recycling of a blend of Polycarbonate and Acrylonitrile Butadiene Styrene (PCABS) sourced from games consoles. The study demonstrated that the use of recycled plastics perform the same technical requirements of virgin plastics[62], and allow relevant environmental[63] and cost saving[64].

The next stage of the analysis is based on the assessment of the product's ecoprofile by assuming a variable use of recycled plastics for the product's manufacturing. The attention has been focused on the three main plastics used in the IJ-MFD: HI-PS, PS and ABS.

The analysis of the recycled content of plastics is performed as follow:

1. Ecoprofile of recycled plastics: to identify, from the scientific and technical literature, the life cycle inventory data of recycled HI-PS, PS and ABS;
2. Datasets implementation: to implement the new inventory datasets for the recycled content assessment
3. Modified Bill of Material: to define possible alternative scenarios based on variable percentages of recycled plastics into components of the IJ-MFD.
4. Impact Assessment: to assess the changes of the environmental impacts of the IJ-MFD.

5.5.1 Ecoprofile of recycled plastics

From the available life cycle inventory databases it was not possible to extract the life cycle inventory data of recycled plastics. Some partial information has been deduced from publication into journals.

Impacts of recycled HI-PS have been estimated by *Ross and Evans, 2002*, for the manufacture of HIPS sheets for packaging. However, except for the 'Global Energy Requirement' (GER) impact category (Table 30), all the other available data reported are mostly aggregated and it was not possible to calculate other impact categories included in the "MEErP Ecoreport" tool.

Note that however the GER represents one the most relevant impact category for HI-PS, ABS and PS, according also to results of Table 13.

LCA of recycled PS and ABS has been not available. This assumption is supported by similarities in the recycling of these plastics (especially ABS and HI-PS[65]). Furthermore, it is noted that other polymers of styrene have similar figures of environmental impacts when recycled (e.g. impacts of recycled EPS as calculated by [Noguchi et al., 1998]). Following these consideration, it has been assumed that impacts of recycled PS and ABS are equal to those of HI-PS.

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[62]Overall, the trials demonstrated that the recycled materials performed to an equivalent standard to the virgin material in almost all the selected applications. Indeed, in some cases the recycled plastics performed to a higher standard than the virgin material currently used [WRAP, 2010].

[63]For example, the results showed that a 50% CO2eq saving could be achieved by replacing virgin HIPS with recycled HIPS into stereo speakers [WRAP. 2010].

[64]For moulding the speaker grills using recycled HIPS, the study successfully demonstrated a potential cost saving of 13% per tonne of material, calculated in September 2009 [WRAP, 2010].

[65] On such topic, see [Brennan et al., 2002].

Table 30 Global Energy Requirement (GER) of recycled plastics

Material	Specific Impact	
	GER	Notes
	MJ/kg	Data for recycled HI-PS estimation [Ross and Evans, 2002]
HI-PS; ABS; PS	18.9	

5.5.2 Datasets implementation.

A new material has been inserted in the "Extra materials" worksheet within the MEErP Ecoreport tool [VHK, 2011]. These data have been then used for the update of the Bill of Material of the IJ-MFD.

5.5.3 Modified Bill of Materials.

Different scenarios are below introduced to analyze the potential changes of the product ecoprofile caused by potential integration of post-consumer recycled plastics into product components. In particular, the impact assessment of the product has been calculated by assuming different percentage of recycled content of HI-PS, ABS and PS according also to previous scenario on the use phase. The BOM of the IJ-MFD (Table 24) has been modified assuming the scenarios presented in Table 31.

Table 31 Scenarios for the analysis of recycled content of plastic components in the IJ-MFD

		Scenarios on recycled conten tof plastics A. (Low utilization)	B. (Moderate Use)	Notes
Scenarios	1. Recycled content of HI-PS, ABS and PS = **10%**	**A.1** HI-PS (virgin: 2101.1 g; recycled: 233.5 g) ABS (virgin: 937.6 g; recycled: 104.2 g) PS (virgin: 690.8 g; recycled: 76.8 g) Energy consumption: 18.28 kWh/year	**B.1** HI-PS (virgin: 2101.1 g; recycled: 233.5 g) ABS (virgin: 937.6 g; recycled: 104.2 g) PS (virgin: 690.8 g; recycled: 76.8 g) Energy consumption: 21.99 kWh/year	Recycled content of plastics into product = 8.4%
	2. Recycled content of HI-PS, ABS and PS = **20%**	**A.2** HI-PS (virgin: 1867.6 g; recycled: 466.9 g) ABS (virgin: 833.4 g; recycled: 208.4 g) PS (virgin: 614.1 g; recycled: 153.5 g) Energy consumption: 18.28 kWh/year	**B.2** HI-PS (virgin: 1867.6 g; recycled: 466.9 g) ABS (virgin: 833.4 g; recycled: 208.4 g) PS (virgin: 614.1 g; recycled: 153.5 g) Energy consumption: 21.99 kWh/year	Recycled content of plastics into product = 16.8%
	3. Recycled content of HI-PS, ABS and PS = **30%**	**A.3** HI-PS (virgin: 1634.2 g; recycled: 700.4 g) ABS (virgin: 729.2 g; recycled: 312.5 g) PS (virgin: 537.3 g; recycled: 230.3 g) Energy consumption: 18.28 kWh/year	**B.3** HI-PS (virgin: 1634.2 g; recycled: 700.4 g) ABS (virgin: 729.2 g; recycled: 312.5 g) PS (virgin: 537.3 g; recycled: 230.3 g) Energy consumption: 21.99 kWh/year	Recycled content of plastics into product = 25.2%
	4. Recycled content of HI-PS, ABS and PS = **40%**	**A.4** HI-PS (virgin: 1400.7 g; recycled: 933.8 g) ABS (virgin: 625.1 g; recycled: 416.7 g) PS (virgin: 460.6 g; recycled: 307.0 g) Energy consumption: 18.28 kWh/year	**B.4** HI-PS (virgin: 1400.7 g; recycled: 933.8 g) ABS (virgin: 625.1 g; recycled: 416.7 g) PS (virgin: 460.6 g; recycled: 307.0 g) Energy consumption: 21.99 kWh/year	Recycled content of plastics into product =33.5%

5.5.4 Impact Assessment

Data of Table 31 have been implemented in the "input" worksheet of the "MEErP Ecoreport" tool for the impact assessment. The new scenarios have been compared to "base-case" scenarios of Table 29. The comparison has been restricted to only the GER impact category due to availability of data for recycled plastics.

Figure 8 illustrates the variations of the GER of the IJ-MFD related to variations of the recycled content of HI-PS, ABS and PS plastics; Figure 9 plots the variations of the GER of the IJ-MFD versus the overall recycled content of plastics in the product.

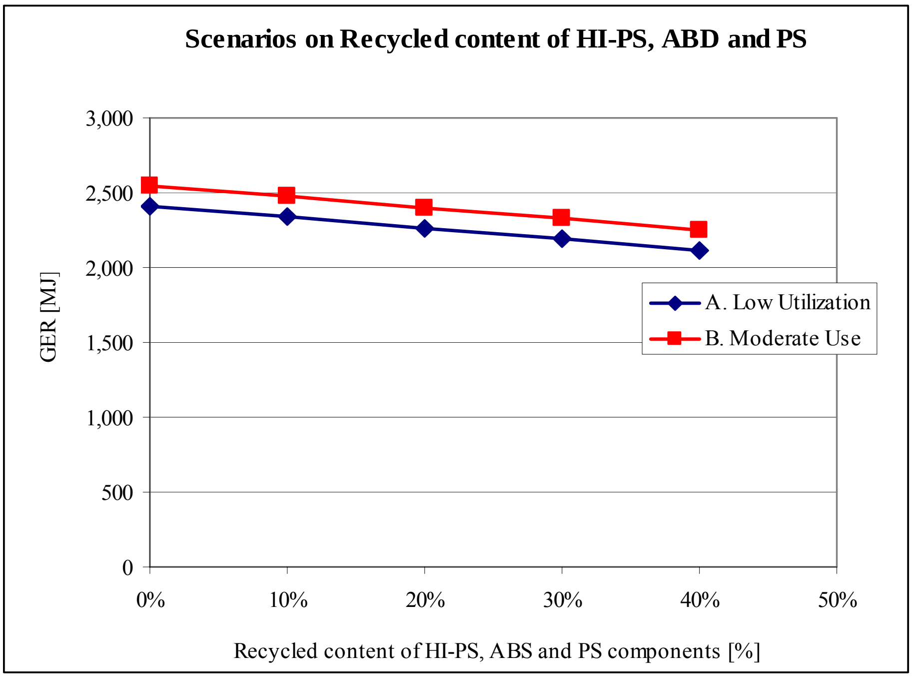

Figure 8. GER of the IJ-MFD with different percentage of recycled HI-PS, Ps and ABS

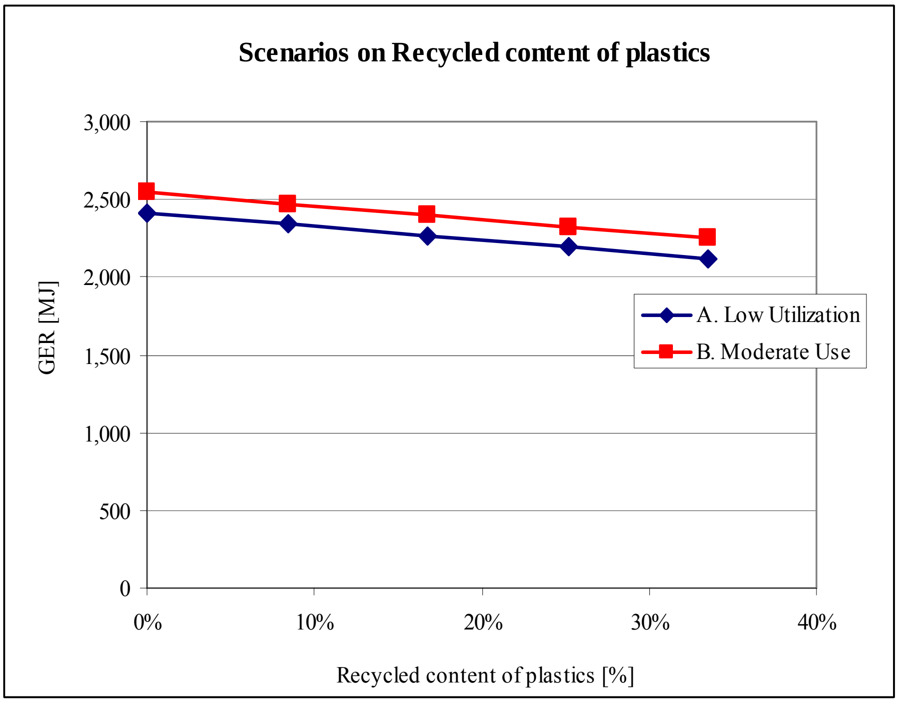

Figure 9. GER of the IJ-MFD with different percentages of the recycled content of plastics

Finally Figure 10 illustrates the variations of the GER of the different scenarios (in comparison with the base-cases) due to different amount of the recycled content of plastics in the product.

It is possible to note that relevant reduction (up to 10%) of the GER can be obtained by using recycling plastics in the product manufacture. In particular, with a 10% recycled content of plastics in the product it is achieved a reduction of the GER of around 3.5% ÷ 3.7% (depending on the utilization scenario). With a recycled content of 30% the decrease of the GER is around 10.5% ÷ 11%.

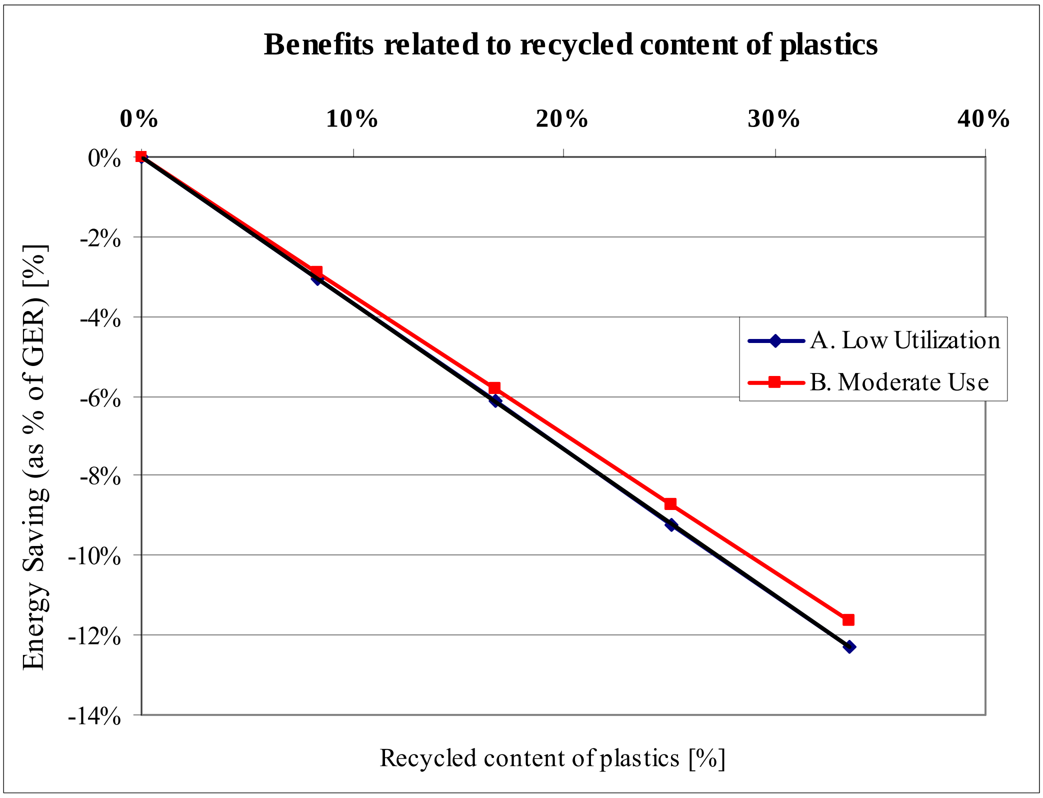

Figure 10 **Variation of the GER of the case-study product with different percentages of recycled content of plastics**

5.6 Potential Requirements on Imaging Equipment

a. Identification of the requirement

According to some recyclers, there are evidences of high demand of high quality recycled plastics, which confirm the assumptions of Figure 9 and Figure 10, even with higher recycled content. Therefore, results of Figure 9 and Figure 10 can be used to identify potentially relevant requirements on recycled content of plastics for the imaging equipment product group.

According to the typologies identified in Chapter 3, the potential product's requirements could relate to declaration and/or thresholds of the recycled content of plastics in the product. Declarative requirements could be preparatory to the setting of thresholds. An example of requirements is following illustrated.

Potential Requirement: Recycled content of plastics for Imaging Equipment

Ink Jet – Multi Function Devices should have at least 10% of Recycled Content of post-consumer plastics (calculated according to the provided method).

Verification:

Manufacturer shall provide a declaration to this effect, together with appropriate supporting documentation, including:

- documented practises that assure the traceability of the product and its constituting materials and components (according to the standard EN 15343 [CEN15343, 2007]);
- records of the amount and types of recycled materials used in the product for the previous four consecutive quarters preceding the declaration.
- declarations from each supplier of post-consumers recycled materials (or of components embodying post-consumers recycled materials).;
- records that demonstrate an active business relationship with each supplier of recycled post-consumers materials.

However, potential difficulties related to the verification process should be considered. On such purpose requirements on recycled content could be more suitable for some product's policy as, for example, more oriented to the implementation in voluntary instruments (e.g. product's environmental labelling systems).

Furthermore, the setting of the requirements on the recycled content should also follow a more comprehensive market analysis, to assess the availability of recycled plastics for the manufacturing, the technical feasibility of using recycled plastics in the product, and the impact that such requirement on a single product category alone may have on displacing the existing flows/volumes of recycled plastic rather then increasing total amount of recycled plastics.

b. Assessment of the requirement at the case-study product level

According to results of Figure 9 and Figure 10, a 10% of recycled plastics in the IJ-MFD can potentially reduce the overall GER of about 3.5% in both the utilization scenarios. This reduction corresponds to the average saving of about 74.1 MJ per product.

Although no detailed figure is available for other impact categories, it is estimated that, similarly to GER, the requirement could produce analogous reductions of the GWP and Acidification potential. The requirement could also produce lower savings for the Eutrophication and Photochemical ozone formation potentials. It is also estimated that the requirement would not affect relevantly the Abiotic depletion potential – elements, the human toxicity and the ecotoxicity impacts.

5.7 Summary and conclusions

The present chapter presented the analysis of the recycled content for plastics for the product group of imaging equipment. The case-study product of 'Ink-Jet multi functional device' has been identified as potentially relevant for the EU market in the next decades.

The analysis has been based of data and information from the EuP preparatory study for Ecodesign implementing measures for the "Imaging Equipment" product category. Methods for the assessment of the Recycled content indices of Report n° 3 have been applied.

Different scenarios have been analyzed, based on different assumptions concerning the percentages of recycled plastic for the manufacturing of the product and the implementation of the different ecoprofile of recycled plastics in the MEErP ecoreport tool

The analysis concluded that relevant environmental benefits in terms of life-cycle energy saving could obtained by using recycling plastics in the product manufacture. For example, with a 10% recycled content of plastics in the product it is achieved a reduction of the GER of about 3.5%; with a recycled content of 30% the GER decreases of about 10%. Such figures could be applied for the setting of potential relevant ecodesign requirements (both declarative and thresholds) for the recycled content of plastics in the case-study product. However, it is highlighted that the analysis of the recycled content has been affected by some uncertainties due to life-cycle impacts of recycled plastics.

Furthermore, the setting of the requirements on the recycled content should also follow a more comprehensive market analysis, to assess the availability of recycled plastics for the manufacturing, the technical feasibility of using recycled plastics in the product, the feasibility of verifying such requirement and the impact that such requirement on a single product category alone may have on displacing the existing flows/volumes of recycled plastic rather then increasing total amount of recycled plastics.

6. Case-study: Washing Machines

6.1 Introduction

The following sections apply the methods for the calculation of the RRR ratios, and RRR Benefit ratios and for the assessment of the use of hazardous substances (as introduced and discussed in Report n° 3) to two case-study washing machines (WM)[66]. Afterwards, the method for the identification and assessment of potentially relevant requirements (as in Chapter 4) is applied.

6.2 Definition of the End-of-Life scenario of washing machine

The first step for the calculation of the RRR indices is the definition of the 'EoL scenario'[67]. According to guidance documents developed (see Report n° 3 – section 1.3.2), product's parts have to be subdivided in the following groups: reusable parts; parts for selective treatments; parts for selective recycling; parts difficult to process; other parts (for material separation).

The research has been focused on the definition of an EU representative EoL scenario (Table 32), defined according to communications with several European recycling companies and one European recycling scheme. EoL scenario is composed of the following treatment (Figure 11): a manual dismantling process; a coarse shredding process; a handpicking process; a fine shredding process; an automatic sorting process; further treatments of outputs.

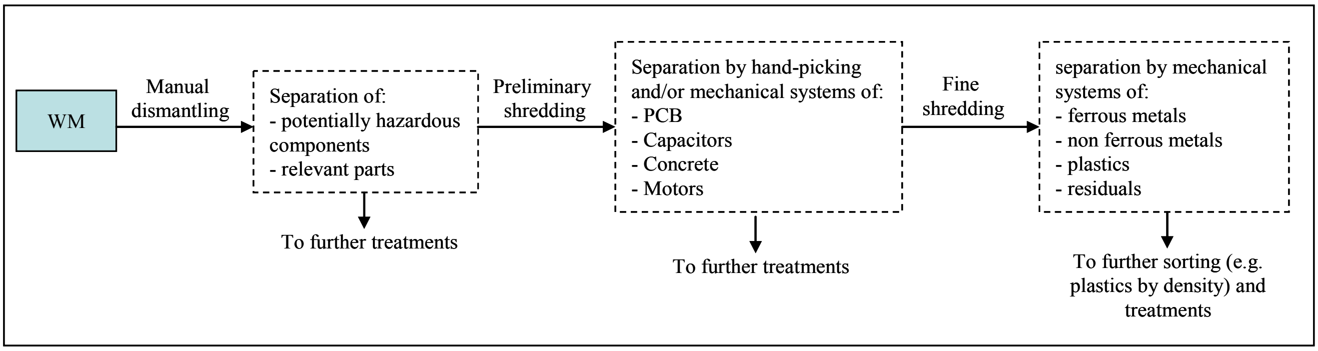

Figure 11 Scheme of the EoL treatments of washing machines

Alternative EoL scenarios are possible and these will be introduces in the discussion of potential Ecodesign requirements in section 6.6).

[66] The analysis of recycled content has been not applied here because already illustrated for the imaging equipment case-study. The analysis of durability will be described in Report n° 1.

[67] The EoL treatment scenario represents the "description of an end of life treatment process and corresponding recycling rates of product parts and materials" [IEC/TR 62635, 2012].

Table 32 EoL scenario of WM

Part	Conditions	Pre-processing	Further treatment
Parts to be re-used (if any)	- parts can be dismantled in a non-destructive way; - commercial reuse/refurbishment systems established	manual dismantling	Reuse
Capacitors (embodied into PCBs) larger than 2.5 diameter	Manually separated, if the PCB where these are installed is manual dismantled	manual dismantling	Landfill / incineration
	otherwise	pre-shredding + handpicking	Landfill / incineration
PCB (larger than 10 cm^2)	if T < 40 sec	manual dismantling	Recycling
	otherwise	pre-shredding + handpicking	Recycling
PCB (smaller than 10 cm^2)		pre-shredding + handpicking	Recycling
Plastic containing brominated flame retardants		Shredding + density separation	Landfill / Recovery
LCD screens (if any)	if surface >100 cm2 (or with backlighting systems)	manual dismantling	Landfill
	other LCD (if T<30 sec)	manual dismantling	Landfill
	other LCD (if T >30 sec)	pre-shredding + handpicking	Landfill
External electrical cables	extracted (no specific problems)	manual dismantling	Recycling
Internal Electrical cables	if accessible during the dismantling of other components (T < 10 sec)	manual dismantling	Recycling
	if T > 10 sec	shredded	Landfill
Electrical motors	if T < 50 sec	manual dismantling	Recycling
	otherwise	pre-shredding + handpicking	Recycling
Large plastic parts	if T < 30 (and mass larger than 200g)	manual dismantling	Recycling
	otherwise	shredded + mechanical separation	Recycling
Other plastic parts		shredded + mechanical separation	Recycling / Energy recovery
External pipes		manual dismantling	Landfill / Energy recovery
Chipboard	if T < 30 sec	manual dismantling	Landfill / Energy recovery
	otherwise	shredded	Landfill / Energy recovery
Front door (glass)		manual dismantling	Landfill
Counterweights	if T < 60 sec	manual dismantling	Landfill (cement); recycling (cast-iron)
	otherwise	shredded + mechanical separation (for cast-iron)	
Other metal parts		shredded + mechanical separation	Recycling

The following sections present the EoL scenario of the WM in more detail and illustrate how parts of WM have been classified according to the different treatments.

Unless differently specified, recycling/recovery rates for different parts refer to the IEC/TR 62635 [IEC, 62635, 2012]. It is however highlighted that some recycling treatments change over the time and time representativeness of such data is not known. Updated data for some parts can be necessary (e.g. concerning the treatment of the concrete, as discussed in section 6.2.4).

6.2.1 Reusable parts

No reusable parts have been currently detected in the WM. However, it is not excluded that some reusable parts could be introduced in future designed product. For this reason, reusable parts (if any) have been introduced in the scenario[68].

6.2.2 Parts for selective treatments

According to the WEEE Directive[69], the following parts have to be removed (by manual dismantling or pre-shredding[70] with manual sorting) from the collected WM:

- Capacitors
- Printed circuit boards
- External electric cables
- plastic containing brominated flame retardants (if any)[71]
- liquid crystal displays – LCD - (together with their casing where appropriate) of a surface greater than 100 cm^2 and all those back-lighted with gas discharge lamps (if any)

Capacitors containing polychlorobiphenyl[72] or those larger than minimum diameter (2.5 cm) have to be extracted. Capacitors are generally embodied into circuit boards[73], although some separated capacitors can be found (especially in old devices). It has been observed that capacitors are generally manually extracted from the PCBs (when these are manually separated). Otherwise capacitors are separated after pre-shredding (by hand-picking). Currently, capacitors containing polychlorobiphenyl are incinerated, while other capacitors are landfilled. Recycling of capacitors is not currently performed at industrial level[74]. However, recycling of capacitors could become a relevant issue in the next future due to their large content of various CRMs (including tantalum and rare earths).

[68] Note that the reuse of products includes several different activities e.g. the partial or full reuse of a product, the remanufacturing, and the refurbishment for the production of second-hand products or for humanitarian purposes. However, here is only considered the reuse of some components of the products by the company that manufactured the product. Further details on reuse and remanufacturing have been discusses in the EP1 – Reports n° 1 and 2.

[69] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)

[70] The "pre-shredding" treatment is also known with other names, including soft-shredding or slow shredding.

[71] Brominated flame retardants (BFR) should be divided into two categories: polybrominated biphenyls (PBB) Polybrominated diphenyl ethers (PBDE) that have been phased out by legislation and are almost not contained anymore in WEEE [Tange et Slijkhuis, 2009], and other BFR that are not restricted and currently in use. Only this last category of BFR has been considered in the current analysis.

[72] According to communications from recyclers, capacitors containing polychlorobiphenyl are not embodied anymore in modern products.

[73] Dismantling of capacitors is therefore related to the dismantling of PCB.

74 Based on private communications from recyclers.

It has been noticed that PCB are generally manually extracted when 'easy to disassembly', i.e. easy to be identified and dismantled in a short time (time for disassembly 'T' assumed below 40 seconds[75]). Printed circuit Boards that are difficult to be identified / extracted are separated after shredding[76].

It is noticed that the WEEE Directive establishes also the extraction of plastic containing some brominated flame retardants. Their separation is generally performed by mechanical separation (by density) after shredding. Such plastics are landfilled or energy recovered[77]. These plastics can be mechanically recycled, but only if manual sorting is performed[78, 79].

Separation of external cables does not imply particular problems (cables cut and separated for recycling).

Liquid crystal displays (LCD) are installed in new high-technological products with complex electronic components. Although the surface of LCD in WM is generally expected to be lower than the WEEE threshold of 100 cm^2, it could be necessary their extraction due to the potential content of hazardous substances in the lighting systems and because potentially contaminating for other recyclable fractions[80]. In this case the LCD can be considered as a "part difficult to process". Furthermore, LCD screen could contain relevant materials including some CRMs (e.g. indium). The number of WM with LCD screens at EoL is currently not relevant, but it is expected to grow in the next years.

Recycling/recovery rates of different parts can be derived from IEC/TR 62635 relatively to the European context [IEC/TR 62635, 2012].

6.2.3 Parts for selective recycling

Parts for selective recycling are those embodying one or more recyclable materials which are economically worth being manual dismantled and separately recycled. This is performed if there is a convenience (environmental and economic) on doing it. On such purpose it is reminded that parts with

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[75] This average threshold has been estimated on the basis of direct observations of disassembly treatments in three recycling plants.

[76] It is reminded that the separation of printed circuit board after shredding causes parts of the board to be mixed with unsorted plastics. This causes larger losses especially of valuable and materials (as discussed in Report n° 3 – Chapter 2).

[77] Technologies for treating plastics with brominated flame retardants include: feedstock recycling, substitution of conventional fuels, pyrolysis, co-combustion with other plastics [Tange et Slijkhuis, 2005].

[78] To mechanically recycle post-user plastic waste containing brominated flame retardant, it has to be collected, sorted, separated, ground, washed and reprocessed before it can be mixed with virgin plastics of the same type for molding new products, or used on its own for alternative lower value products [BSEF, 2012]. Only in a limited number of cases are the overall plastics recycling operations economically viable because of the relatively low cost of new, virgin plastics.

[79] It is currently observed an intensive research to develop processes for the recycling of plastics with flame retardants. There are some evidences in the scientific literature of technologies for the sorting of plastics with flame retardants, as for example by X-ray fluorescent (XRF) spectroscopy combined with other systems (including Near Infrared Spectroscopy and other techniques), thanks to which different types of flame-retardants (FRs) can be identified and pure resin with FRs can be separated [Di Maio et al., 2010]. However the representativeness of their use in the EU is not available. Data from IEC/TR 62635 have been assumed as the most representative currently available.

[80] According to experience of recyclers, LCD screens can contaminate other PCBs lowering the value of recyclable parts and decreasing recycling rates of electronics.

recyclable materials have to fulfil the following conditions, as suggested by the IEC/TR 62635 [IEC/TR 62635, 2012]:

- "*The size of the part and nature of material is such that there is an economical interest for dismantling […]*
- *There is a specific EoL channel for these materials with higher recycling rates compared to the results obtained after material separation*".

In the WM these parts are:

- motors
- internal cables
- large plastic parts

Concerning the recycling of the motor the IEC/TR 62635 assumes it is extracted preventively before shredding because part potentially difficult to process [IEC/TR 62635, 2012]. The IEC/TR estimates on average a recycling rate of 85% (without any detail on different figures for different materials). However, it has been observed in recycling plants that motors are sometimes extracted after a preliminary shredding. According to studies in the scientific literature, shredding of the motors causes the materials to be more difficult to be separated, with larger losses (see for example [Castro et al., 2004]). In the next sections it is assumed to differentiate the recycling rates of metals in the motor as following (estimated values)[81]:

- motor manually disassembled: recycling/recovery rates of 95% for steel and 90% for copper;
- motor sorted after pre-shredding: recycling/recovery rates of 90% for steel and 85% for copper.

Internal electrical cables are partially extracted during the disassembly of other components. However, cables difficult to be accessed are neglected. Cables not extracted are shredded and collected with unsorted materials. Recycling rates of separated internal cables are derived from IEC/TR 62635 [IEC/TR 62635, 2012]. For shredded cables, recycling/recovery rates are assumed 0%[82].

Concerning recyclable plastics, homogeneous parts in PP/ABS/PS larger than 200g and easy to be dismantled (T<30 sec) are worth to be manually separated and addressed to specific EoL channels. In WMs, parts accomplishing to these conditions are generally in the front door. However, other homogenous plastic parts could be worth for separate recycling, including control panel and worktop frame. Recycling/recovery rates for various plastics can be derived from IEC/TR 62635.

[81] Values for recycling rates of motors parts have been estimated by JRC on the basis of similar figures in the IEC/TR 62635 for other components.
[82] It has been observed that unsorted shredded cables in WMs are contaminated by several other fractions (including e.g. concrete and other plastics) that make very difficult the recovery of contained copper.

6.2.4 Parts difficult to process

Parts difficult to process are those that have to be preventively extracted because potentially interfering with the following separation processes (e.g. parts that can block or damage the shredders and the cutting systems).

Counterweights (in concrete or cast-iron) can represent a part potentially difficult to be processed. However, the treatment of counterweighs in recycling plants can be very different. Counterweights can block or damage the cutting systems of shredders of small / medium dimensions, while they do not cause problems to large shredding plants. In the EoL scenario it has been assumed that counterweights are extracted if easy to be dismantled (T < 60sec). This generally happens for counterweights installed at the top or bottom of the WM. Otherwise, counterweights are shredded and partially separated by mechanical systems.

Cast-iron counterweights can be easily recycled after shredding and automatic sorting. On the other hands, the recycling of concrete, although technologically possible, is generally not performed also due to the low value of this fraction. It has been observed that some companies recycle inert materials from WMs for the construction of roads. However, the representativeness in the EU27 of these treatments and their recycling rates are not public available. For these reasons, figures from the IEC/TR 62635 have been considered assuming a 0% recycling/recovery rate of concrete from EEE [IEC/TR 62635, 2012].

Other parts difficult to be processed by small-medium shredders are:

- Glass: generally located in the front door, glass is abrasive for the cutting system. It is generally separated without particular difficulties.
- Wood: chipboards are generally located on the worktop frame, jointly with some plastics. Wood can interfere with cutting systems, and it is separated when easy to be dismantles (T<30 sec)
- External EPDM/rubber pipes: generally located in back of the WM, can obstruct the cutting system. These are generally separated without particular difficulties;
- Cotton mats (used as insulation). These could obstruct small shredders.

According to the IEC/TR 62635, recycling/recovery rates of glass are null, although it has been observed that some recycler are currently setting-up some recovery routes.

No data available concerning the cotton mat, which is assumed to be landfilled (recycling / recovery rates 0%).

No data are also available in the IEC/TR 62635 on EPDM and wood. Concerning the EPDM (after manual dismantling) it is assumed: recycling rate (0%); recovery rate (90%). Concerning the wood (both after manual dismantling or mechanical separation) it is assumed: recycling rate (0%); recovery rate (90%).

6.2.5 Other parts (for material separation)

It includes those remaining parts that are processed by one or more shredders in line (with a decreasing cutting size) and afterwards separated by various systems including magnetic separators, eddy-current separators and gravimetric systems. In particular the following materials can be separated for recycling and recovery:

- iron and steel
- aluminium
- copper
- various plastics (mainly PP / ABS / PS).

Recycling / recovery rates for metals and plastics can be derived by IEC/TR 62635 [IEC/TR 62635, 2012].

Residues from the shredding of the WM include:

- plastic residues (not separated by gravimetric systems)
- metal residues (not intercepted by the magnetic and eddy-current separators)

Residues from the shredding are energy recovered or landfilled.

6.3 Bill of material of washing machines case-studies

The bills of materials of the analyzed case-studies are the following[83] (WM1: case-study 1; WM2: case-study 2). According to communications from manufacturers, the WM1 is considered representative of the medium-low price segment of the market, while the WM2 is representative of the high price segment. Packaging is not considered in these BoM.

[83] Data of the WM refer to [Rüdenauer et Gensch, 2005]. The BOM has been complemented by additional information from manufacturers (from private communications). Based on communication of the European Committee of Domestic Equipment Manufacturers (CECED) these BOM are currently representative of the European situation.

Table 33 BOM of WM case-studies

Materials	WM 1		WM 2	
	mass [g]	Percentage of product mass [%]	mass [g]	Percentage of product mass [%]
Acryl-Butadien-Styrol (ABS)	1,228	1.7%	1,196	1.2%
Aluminium	2,313	3.2%	3,608	3.7%
Brass	73	0.1%		
Cable	781	1.1%	952	1.0%
Carboran 40%			775	0.8%
Chipboard	2,057	2.9%	2,468	2.5%
Concrete	22,740	31.7%		
Copper	925	1.3%	1,027	1.1%
Cotton with phenolic binder	525	0.7%	1,620	1.7%
Electronic Components	362	0.5%	1,929	2.0%
Ethylen-Propylen-Copolymer (EPDM)	2,220	3.1%	2,960	3.0%
Glass	1,931	2.7%	1,476	1.5%
Cast iron	1,304	1.8%	28,780	29.7%
Polyacryl (PA)	17	0.02%		
Polyethylen (PE)			27	0.03%
Polymethylmethacrylat (PMMA)	3	0.004%	185	0.2%
Polyoxymethylen (POM)			26	0.03%
Polypropylen (PP)	175	0.2%	489	0.5%
PP 20% mineral filler	421	0.6%	41	0.04%
PP 40% mineral filler	8,012	11.2%	1,410	1.5%
Polystyrene (PS)	219	0.3%		
Steel	24,320	33.9%	44,733	46.1%
Other materials	2,118	3.0%	3,350	3.5%
Total product	***71,744***	100.0%	***97,052***	100.0%

However, previous BOMs do not detail the components of the WM, but only show aggregated figures. Analogously, disassembly data from manufacturers were not available. Composition of main components and their disassembly has been estimated on the basis of communications from recyclers[84]. Details of disassembly are afterwards provided in Table 38 (WM1) and Table 44 (WM2).

[84] The study has been mostly based on data from pre-treatment facilities. However some data from final recyclers have been collected directly or indirectly (thanks to information on the final treatments of materials from pre-treatments facilities or association of recyclers).

Table 34 BOM of WM case-studies (detail of components)

Materials	WM 1 case-study		WM 2 case-study	
	Mass [g]	Details of the content	Mass [g]	Details of the content
Acryl-Butadien-Styrol (ABS)	1,228	360g in the frame of the porthole. Other ABS in various components	1196	360g in the frame of the porthole. Other ABS in various components
Aluminium	2,313	various components (not defined)	3,608	various components (not defined)
Brass	73	various components (not defined)	-	-
Cables	781	50% (390.5g) of external cables	952	50% (476g) external cables
Chipboard	2,057	located at the top of the WM	2,468	located at the top of the WM
Concrete (low armored)	22,740	70% (15.92 kg) located at the bottom of the WM. 30% located internally	-	-
Copper	925	In the motor	1,027	In the motor
Cotton with phenolic binder	525	cotton mat for insulation	1,620	cotton mat for insulation
Electronic Components	362	Printed circuit board (with capacitor: 10g) intermediate in terms of content of precious metals	1,929	Main board (PCB rich: 321g; PP:110g): Secondary board (PCB intermediate:715g; PP frame: 200g; Al heat sink: 200g; Capacitor: 30g); LCD screen 58.5 cm2 (without lamp) with PCB poor (120g) and ABS frame: (233g);
Ethylen-Propylen-Copolymer (EPDM)	2,220	Pipes	2,960	Pipes
Glass	1,931	Front door	1,476	Front door
Gray cast iron	1,304	various components (not defined)	28,780	Cast iron (28kg) used in the counterweight (located at the bottom of the product).
Polyacryl (PA)	17	various components (not defined)	-	various components (not defined)
Polyethylen (PE)	-		27	
Polyoxymethylen (POM)	-		26	
Polymethylmethacrylat (PMMA)	3		185	
Polypropylen (PP)	175		489	
PP 20% mineral filler	421		41	
PP 40% mineral filler	8,012		1,410	
Carboran 40%	-		775	
Polystryrene (PS)	219		-	
Steel	24,320	1.5 kg in the motor. Other steel in various components	44,733	2 kg in the motor; (including in the magnets: neodymium 40g; praseodymium 10g; dysprosium 10g; terbium 5g). Other steel in other components.
Other materials	2,118	various components (not defined)	3,350	various components (not defined)
Washing machine	***71,744***		***97,052***	

Further details is however necessary concerning some key materials and components, especially those embodying relevant materials, including CRMs. This detail is illustrated in the following sections.

6.3.1 Detail of some key components and materials embodied in WMs

6.3.1.1 Printed circuit boards

Printed circuit boards (PCB) represent one of the most relevant components of WM due to their content of relevant and/or potentially hazardous materials. A detail of the composition of different PCBs (poor, intermediate, rich in term of content of precious metals), including some CRMs, is illustrated in Table 35[85].

Table 35 Average composition of different PCBs

Material	Composition of PCBs poor	intermediate	rich
	Percentage [%]		
Glass	30.90%	30.90%	30.88%
Epoxy resin	19.81%	19.80%	19.79%
Ceramic	10.84%	10.84%	10.83%
Copper	19.60%	19.59%	19.58%
TBBP-A	9.10%	9.10%	9.09%
iron	3.57%	3.57%	3.57%
Aluminum	2.21%	2.21%	2.21%
Lead	2.66%	2.66%	2.66%
Nickel	0.43%	0.43%	0.43%
Zinc	0.32%	0.32%	0.32%
Barium	0.32%	0.32%	0.32%
Arsenic	0.001%	0.001%	0.001%
Beryllium	0.0001%	0.0001%	0.0001%
Cadmium	0.000014%	0.000014%	0.000014%
Chromium	0.005%	0.005%	0.005%
Cobalt	0.040%	0.040%	0.040%
Molybdenum	0.000%	0.000%	0.000%
mercury	0.000%	0.000%	0.000%
Antimony	0.1%	0.1%	0.1%
Silver	0.052%	0.070%	0.100%
Gold	0.007%	0.010%	0.025%
Palladium	0.001%	0.002%	0.011%
Platinum	0%	0.0%	0.004%
Total	**100%**	**100%**	**100%**

6.3.1.2 Content of precious metals: gold, silver and Platinum Group Metals (PGM)

Platinum Group Metals (PGMs) are used into electronics including capacitors, connectors, and electrical contacts. In particular Platinum and Palladium are used in Printed Circuit Board (PCB) in percentages variable depending on the scopes and applications of the PCB.

In general, according to the scientific literature and according to information from manufacturers and recyclers, the PCB can be roughly subdivided into three typologies ('poor', 'intermediate' and 'rich' PCB)[86] depending on the content of PGMs and other precious metals[87].

The next Table 36 summarizes average content of PGMs and other precious metals for the different typologies of PCB (estimated data from [ADEME, 2008; UNEP, 2011b]).

It is also noticed that PGMs can be contained in some special capacitors multilayer ceramic capacitors, used for high performing electronic components.

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85 The content of precious metals in the PCB is estimated from [ADEME, 2008; UNEP, 2011b]. The content of other materials in the PCB is estimated from [Mohite, 2005].

86 This distinction is also adopted by the IEC/TR 62635, in Annex D [IEC/TR 62635, 2012].

87 For example, larger amounts of PGMs are used for PCB into mobile phones, laptop, PC, LCD and for PCB of some households (including high efficiency washing machine).

Table 36 Estimated content of PGMs and other precious metals in different typologies of PCB (estimated data from [ADEME, 2008; UNEP, 2011b]).

	Category of Printed Circuit Board		
	Poor' (g/ton)	Intermediate (g/ton)	Rich' (g/ton)
Palladium	8	21	110
Platinum	-	-	40
Silver	520	700	1000
Gold	68	100	250

According to Luda, (2011) the recycling of metals from PCB can currently occur by different processed (including pyrometallurgy and hydrometallurgy). Percentages of recovery of palladium and other precious metals are variable and depend on the treatment that they undergo. The following recycling/recovery rates are assumed (Table 37)[88].

Table 37 Recovery of precious metals by different recovery routes

	Recycling/recovery rate [%]			
	Cu	Ag	Au	Pd
Mechanical sorting [Chancerel et al., 2009]	60%	11.5%	25.6%	25.6%
Manual dismantling [Meskers et al., 2009]	95% *	92%	97%	99%
Cu: Copper; Ag: silver; Au: gold; Pd: Palladium. (*) IEC/TR 62635: recovery of copper from shredded parts				

6.3.1.3 Content of rare earths

In 2008, around 30 % of the global rare earth consumption was used in the glass, polishing and ceramics sectors. Around 20 % were used for permanent magnets, a further 20 % for automotive and industrial catalysts, another 20 % for metal alloys and batteries and around 7 % for lighting [Schüler et al., 2011].

Some rare earths, and in particular, neodymium, are used in magnets of high efficient electric motors of households (including technologically advanced WMs). According to Du et Graedel, (2011) magnets have best performance when the content of neodymium reaches 26.7% by weight. However, the actual percentages of neodymium can vary depending on the materials used for the manufacturing. Furthermore praseodymium coexists with neodymium minerals naturally; it is also common to add terbium and dysprosium in neodymium-iron-boron magnets to improve the high-temperature performance [Du et Graedel, 2011]

[88] Further details on the recycling rate of some metals are discussed in Report n° 3 – Section 2.2.3.

It is therefore assumed that the average percentage in mass of rare earth into permanent magnets for high-efficiency motors is the following: neodymium 20%; praseodymium 5%; dysprosium 5%; terbium 1% (Adapted from [Du et Graedel, 2011]).

It is also noticed that rare earth can be used in small quantities also into ceramic capacitors.

Concerning the recycling of rare earth, only a few industrial recycling activities are currently implemented concerning lamps and batteries [Schüler et al., 2011]. A recent survey estimated that less than 1% of rare earths currently discarded undergo recycling [Graedel et al. 2011].

Some example of recycling of rare earths from other waste flows exists at experimental level. For example there are various studies in China on the recovery of rare earth metals from neodymium magnet scrap and waste, with variable recovery rates from 82% to 99% [Schüler et al., 2011]. Current research is ongoing in Japan into the post-consumer recycling of rare earths from motors/generators (permanent magnets). Pyrometallurgical and hydrometallurgical approaches are described which focus on the recovery of rare earth elements as metals [Takeda 2009, Koyama 2009].

Furthermore, it is noticed that the rare earths from electric motors, hard disks and other electronic components, require intensive dismantling before recycling [Schüler et al., 2011]. On such purpose some scientists suggest investigating whether "the Ecodesign Directive (2009) and related regulations should be adapted in order to support the dismantling and recycling of rare earth components from energy-using products. […] The rare earth recycling should be addressed by specific requirements, e.g. the obligation for dismantling of selected rare earth containing components" [Schüler et al., 2011].

6.3.1.4 Content of antimony

Flame retardants are the primary end-use for antimony and accounted for about 50-70% percent of all consumption [Carlin, 2000; EC, 2012], and can be potentially embodied into WMs. Furthermore, antimony can be used also into PCBs (percentage in mass estimated below 0.1% [Mohite, 2005]).

According to available studies, antimony is not recycled from flame retardant uses, and it can be classified as dissipative use [Carlin, 2000]. There are some evidences of recycling processes of antimony by some precious metal smelter [Brusselaers et al., 2006], however their representativeness in the EU is not available.

6.3.1.5 Content of other critical raw materials

Small quantities of other critical raw materials can be potentially present into some electronic components of WMs (it was, however, not possible to have precise figures of their content in the case-study products), as:

- In capacitors:
    - Tantalum (into electrolytic capacitors);
- In PCBs:
    - Beryllium;
    - Cobalt;
    - Gallium.

- In LCD:
    - Indium

Some of these materials, as beryllium and cobalt, have been detected in the Bill of Materials of the PCB used to model the WM case-studies (according to [Mohite, 2005]).

Cobalt and beryllium from some post-consumers scraps in the market are partially recycled; however, there is no evidence concerning the recycling of these materials from PCB. Recycling / Recovery rates of these materials are assumed 0%.

Recycling of Tantalum from capacitors is difficult and insufficiently developed. The description of some recovery processes has been observed in the scientific literature, e.g. by Mineta et Okabe, 2005, which illustrate a process to recovery up to approximately 90–92% of the Tantalum from the scraps, with a purity of 99%.

Recycling of Indium from LCD from WM is not documented at industrial level (Recycling / Recovery rates of 0%, also in accordance to IEC/TR 62635 [IEC/TR 62635, 2012]). However, some experimental plants for indium recycling are being developed (for example by [Salhofer et al., 2011]). This topic will be discussed more in detail in the LCD-TV case-study.

6.4 Analysis of the case-study: WM1

The following sections illustrate the EoL treatments for the WM1 case-study and the application of methods developed in Report n° 3 for the calculation of the RRR rates and RRR benefit rates.

Table 38 illustrates the EoL scenario applied to the WM1.

Table 38 Table EoL scenario of WM1

Part	Mass [g]	Conditions	Pre-processing	Further treatment	Typology of part
No parts to be reused	-	-	-	-	-
PCB with intermediate content of precious metals, (larger than 10 cm^2) including capacitor	362	Extracted after shredding (T > 50s). Capacitor separated after shredding	pre-shredding + handpicking	Recycling (capacitor landfilled)	Part for selective treatment
Plastic containing brominated flame retardants (not detected)	-	-	-	-	-
LCD screens (not detected)	-	-	-	-	-
External Electrical cables	390.5	No problems detected to disassembly	manual dismantling	Recycling	Part for selective treatment
Internal Electrical cables	390.5	Not dismantled (T > 10 sec)	shredded	Landfill	Other parts (for material separation)
Electrical motors	2,425	Not dismantled (T > 50 sec)	pre-shredding + handpicking	Recycling	Other parts (for material separation)
Large plastic parts: ABS front door	360	dimantled (T < 30 sec)	manual dismantling	Recycling	Part for selective recycling
Other plastic parts (various)	9,715	-	shredded + mechanical separation	Partial Recyling / Recovery	Other parts (for material separation)
External pipes	2,220	No problems detected to disassembly	manual dismantling	Landfill / Energy recovery	Part difficult to process
Chipboard	2,057	Dismantled (T < 30 sec)	manual dismantling	Landfill / Energy recovery	Part difficult to process
Front door (glass)	1,931	No problems detected to disassembly	manual dismantling	Landfill	Part difficult to process
Bottom counterweights (concrete)	15,920	Dismantled (T < 60 sec)	manual dismantling	landfill	Part difficult to process
Internal counterweights (concrete)	6,820	not dismantled (T > 60 sec)	shredded	landfill	Part difficult to process
Other metal parts (cast-iron, steel,aluminium)	26,510	-	shredded + mechanical separation	Recycling	Other parts (for material separation)
Other materials (cotton mat + unspecified materials)	2,643	-	shredded	landfill	Other parts (for material separation)

6.4.1 Calculation of the RRR rates for the case-study WM1

The following section describes the calculation of the RRR rates for the WM1 according to the considered EOL scenario.

6.4.1.1 Reusability rate

No reusable parts are detected. Reusability rate of the WM1 is: $R_{Use} = 0\ \%$.

6.4.1.2 Recyclability rate

The Recyclability rate is calculated in the following data-sheet. It results that the Recyclability rate of the WM1 is: $R^{*}_{cyc} = 39\ \%$.

For the calculation it has been assumed that recycling rate of PCB is 11.8% (based on Table 37).

It is possible to observe that the Recyclability of the WM1 is very low, also being far from the recycling percentages established by the Annex V of the recast of the WEEE Directive [European Council, 2012]. However, it is highlighted that the index here discussed focuses on the 'recyclability' as potential at the design stage, while the WEEE Directive refers to target values of recycled WEEE among some macro-categories[89].

Main reasons for the low value of the recyclability of WM1 are:

- Concrete blocks represent around 30% of the overall mass. It was assumed with a recyclability of 0% (according to [IEC/TR 62635, 2012]). However, based on communication from recyclers, there are some evidences that concrete blocks, especially those manually extracted, are partially recycled for the construction of roads. If different recycling rates are assumed, figures of the WM1 will increase largely. A more comprehensive analysis of flows of concrete at the recycling plants would help to refine such estimations and potentially revising figures from IEC/TR 62635.

- Polypropylene parts of the WM1 are largely not recyclable. This is due to the mechanical separation systems (by gravity) that do no allow to sort plastics with additives. Avoiding the use of additives in the PP could increase the Recyclability of the WM1 (up to around 10% more). On the other hands such additives are necessary for some functional technical reasons (mainly an increased resistance to heat).

[89] It is also highlighted that the targets of the WEEE Directive based on the measured amount of wastes treated in the recycling plants, while the calculation of the recyclability rates are based on the assumed values of recycling/recovery rates of different materials/components as in the IEC/TR 62635 (including also the efficiency of the separation of the materials and their effective losses).

Table 39 Calculation of the Recyclability rate of the WM1

Product Details					
Product	Mass (m) of the product [kg]				
Washing machine (WM1)	71.744				
Parts for selective treatment:					
Part	Materials	Mass ($m_{recycl,i}$) [kg]	Recycling rate (RCR_i) [%]	($m_{recycl,i}$*RCR_i) [kg]	References/details for the (RCR)
External cables	Copper and plastics	0.39	24%	9.4E-02	low current cable from IEC 62635
Parts for selective recycling:					
Part	Materials	Mass ($m_{recycl,i}$) [kg]	Recycling rate (RCR_i) [%]	($m_{recycl,i}$*RCR_i) [kg]	References/details for the (RCR)
Front door frame	ABS	0.36	94%	3.4E-01	IEC 62635
Parts difficult to process:					
Part	Materials	Mass ($m_{recycl,i}$) [kg]	Recycling rate (RCR_i) [%]	($m_{recycl,i}$*RCR_i) [kg]	References/details for the (RCR)
Chipboard	wood	2.06	0%	0.0E+00	no data available
Concrete block (external)	Concrete (light armored)	15.92	0%	0.0E+00	IEC 62635
Rubber pipes	EPDM	2.22	0%	0.0E+00	IEC 62635
Front door	Glass	1.93	0%	0.0E+00	IEC 62635
Other parts (for material separation):					
Part	Materials	Mass ($m_{recycl,i}$) [kg]	Recycling rate (RCR_i) [%]	($m_{recycl,i}$*RCR_i) [kg]	References/details for the (RCR)
Aluminium components (various)	Aluminium	2.31	91%	2.1E+00	IEC 62635
Steel components (various)	Steel	22.82	94%	2.1E+01	average steel from IEC 62635
Brass components (various)	Brass	0.07	70%	5.1E-02	estimation from IEC 62635 (other metals)
Cast iron components (various)	cast-iron	1.30	60%	7.8E-01	assumed as non magnetic steel (from IEC 62635 from Korean data)
Motor	Steel	1.5	90%	1.4E+00	Estimation
	Copper	0.925	85%	7.9E-01	
Printed circuit board	Various	0.352	11.8%	4.1E-02	recycling rate estimated from various references concerning the recycling of copper and precious metals
	Capacitor (various)	0.01	0%	0.0E+00	IEC 62635
Internal cables	copper and plastics	0.39	0%	0.0E+00	Estimation
ABS components (Various)	ABS	0.87	74%	6.4E-01	IEC 62635
Polyacryl (PA) (various)	PA	0.02	0%	0.0E+00	IEC 62635
Polymethylmethacrylat (PMMA) (Various)	PMMA	0.003	0%	0.0E+00	IEC 62635
Polypropylen (PP) components (various)	PP	0.18	90%	1.6E-01	IEC 62635
Polypropylen (PP) components (various)	PP with additives (mineral fillers)	8.43	0%	0.0E+00	IEC 62635
Polystryrene (PS) (Various)	PS	0.22	83%	1.8E-01	IEC 62635
Residual concrete blocks	Concrete (light armored)	6.82	0%	0.0E+00	IEC 62635
Insulation mat	Cotton with phenolic binder	0.53	0%	0.0E+00	no data available
Other materials	Various	2.12	0%	0.0E+00	no data available
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				27.98	
Recyclability rate (R^*cyc) [%]		39.0%			

6.4.1.3 Recoverability rate

The Recoverability rate is calculated in the following data-sheet. Recoverability rate of the WM1 is: R_{cov} = *45.6%*.

Table 40 Calculation of the Recoverability rate of WM1

Product Details					
Product	Mass (m) of the product [kg]				
Washing machine (WM1)	71.744				
Reusable Parts:					
Part		Mass ($m_{reuse,i}$) [kg]	Evidences for the reuse of the part		
No reusable parts detected		0			
Parts for selective treatment:					
Part	Recoverable materials	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	($m_{recov,i}$*RVR_i) [kg]	References/details for the (RVR)
External cables	Copper and plastics	3.9E-01	24%	9.4E-02	low current cable from IEC 62635
Parts for selective recovery:					
Part	Recoverable materials	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	($m_{recov,i}$*RVR_i) [kg]	References/details for the (RVR)
Porthole frame	ABS	0.36	95%	0.342	IEC 62635
Parts difficult to process:					
Part	Recoverable materials	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	($m_{recov,i}$*RVR_i) [kg]	References/details for the (RVR)
Chipboard	wood	2.06	90%	1.9	Estimation
Concrete block (external)	Concrete (light armored)	15.92	0%	0.00	IEC 62635
EPDM pipes	EPDM	2.22	90%	1.998	Rubber (IEC 62635)
Porthole	Glass	1.93	0%	0	IEC 62635
Other parts (for material separation):					
Part	Recoverable materials	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	($m_{recov,i}$*RVR_i) [kg]	References/details for the (RVR)
Aluminium components (various)	Aluminium	2.31	91%	2.10	IEC 62635
Steel components (various)	Steel	22.82	94%	21.45	average steel from IEC 62635
Brass components (various)	Brass	0.07	70%	0.05	Other metals (IEC 62635)
Cast iron components (various)	cast-iron	1.30	60%	0.78	assumed as non magnetic steel (from IEC 62635)
Motor	Steel	1.5	90%	1.35	Estimation
	Copper	0.925	85%	0.78625	
Printed circuit board	board (various)	0.352	60%	2.1E-01	IEC 62635 (intermediate board)
	capacitor (various)	0.010	0%	0	IEC 62635
Internal cables	copper and plastics	0.39	24%	0.1	estimation (from IEC 62635)
ABS components (Various)	ABS	0.87	75%	0.65	IEC 62635
Polyacryl (PA) (various)	PA	0.02	5%	0.001	assumed as 'other plastics' (IEC 62635)
Polymethylmethacrylat (PMMA) (Various)	PMMA	0.003	5%	1.5E-04	estimation from (IEC 62635)
Polypropylen (PP) components (various)	PP	0.18	91%	0.16	IEC 62635
Polypropylen (PP) components (various)	PP with additives (mineral fillers)	8.43	5%	0.42	IEC 62635
Polystryrene (PS) (Various)	PS	0.22	84%	0.18	IEC 62635
Residual concrete blocks	Concrete (light armored)	6.82	0%	0	IEC 62635
Insulation mat	Cotton with phenolic binder	0.53	0%	0	no data available
Other materials	Various	2.12	0%	0	assumed to be landfilled
Sum of recoverable parts ($\Sigma m_{reuse,i}$ + $\Sigma m_{recov,i}$ * RCR_i) [kg]				**32.7**	
Recoverability rate (*R cov)* [%]		**45.6%**			

6.4.2 Calculation of the RRR Benefit rates for the case-study WM1

The following sections apply the methods for the calculation of the RRR Benefits rates as introduced and discussed in Report n° 3 – Chapter 2.

6.4.2.1 Life cycle impacts of the WM1

Life-cycle impacts of the WM1 are necessary for the calculation of the RRR benefits ratios. For the calculation of the Life-cycle impacts of the WM1 the following assumptions have been applied:

- Assumption about the production of materials:
  - Bill of Materials: as in Table in Section 6.3.
  - Life-Cycle-Inventory data of materials from various references [ecoinvent; ELCD, 2010; PE; BUWAL, 1996; PlasticsEurope];
  - Impacts of packaging not considered.
- Assumption about the manufacturing phase:
  - Energy consumption for the manufacturing, 37.5 kWh of electricity for device (estimation from [Rüdenauer et Gensch, 2005]). Inventory data of electricity from [ELCD, 2010];
  - Energy consumption for the manufacturing of the PCB estimated from [Williams, 2004];
  - Transport of raw materials not considered (assumed not relevant).
- Assumptions about the use phase[90]:
  - useful life: 11.4 years [Rüdenauer et Gensch, 2005];
  - average energy consumption: 0.76 kWh/cycle[91];
  - number of cycles. 175 cycles/year [Rüdenauer et Gensch, 2005];
  - consumption of water: 35.6 kg/cycle[92];
  - consumption of detergents: 80 g/cycle (estimation from information of detergent producers);
  - Distribution of the product to consumers (estimation): (inventory data of emissions for transport from [ELCD, 2010]);

---

[90] It is highlighted that figures about the use phase refer to future estimations from [Rüdenauer et Gensch, 2005]. These figures can be higher than the consumption of current product. However, lower consuptions during the use phase would increase the relevance of other life-cycle stages (including EoL).

[91] Estimation for 4 kg load washing cycle based on [Rüdenauer et Gensch, 2005].

[92] Estimation for 4 kg load washing cycle based on [Rüdenauer et Gensch, 2005].

- Assumptions about the EoL;
    - Inventory data about the landfill of metals, plastics and inert from [ELCD, 2010].
    - Life-Cycle-Inventory data of recycled materials from various references [BUWAL, 1996; ecoinvent; PE];
    - Impacts due to the sorting of materials have been neglected[93].

6.4.2.2 Reusability benefit rate

No reusable parts are detected in the case-study. The Reusability benefit rate is therefore 0%.

6.4.2.3 Recyclability benefit rate

For the calculation of the Recyclability benefit rate, recycling rates of materials are those used for the Recyclability rate index, with the following additional assumptions:

- Recycling rates of copper, gold, silver, platinum and palladium are those introduced in Table 37
- Recycling rates of plastics from PCB are assumed null (thermoset plastics not recyclable).

Table 41 illustrates the calculation of the recyclability benefit ratio for the indicator "Abiotic depletion elemental". It results that the Recyclability benefit ratio amounts to: 46.6%. It means that, the current EoL treatments allow recovering 46.6% of the life-cycle ADP impact of the product.

Table 42 and Figure 12 illustrate the recyclability benefit ratio calculated for other impact categories. In particular, Table 42 illustrates the LCA impacts of the product for the various impact categories and the benefits that can be achieved due to current EoL treatments.

It is important to underline that contribution of plastics to recyclability benefit index is not accounted due to missing life-cycle inventory data of recycled plastics. It is estimated that their contribution would be negligible for the ADP elemental impact category.

The contribution of plastics could be potentially relevant for other impacts categories (as e.g. ADP fossil). However, the content of plastics in the product is not very relevant (around 15%), and these are therefore neglected in the benefit analysis.

[93] Impacts due to the manual/mechanical sorting consist mainly of electricity consumed by tools or machines (e.g. shredders). However, it is assumed that electricity consumption is dominated by the use phase (according also to other study in the literature [ISIS, 2007]) and consequently electricity consumption for sorting is neglected. Other emissions during the recycling (e.g. release of dust and chemicals) and other potential environmental impacts (e.g. noise levels, safety of workers) have been not included because no inventory data were available.

Table 41 Calculation of the Recyclability Benefit rate of WM1

Product Details	
Product	**Mass (m) [kg]**
Washing machine (WM1)	71.744
Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential elemental (ADP)
Unit of measure	kg $Sb_{eq.}$

Recyclable parts:

Recyclable part	Material	Mass ($m_{recyc,i}$) [kg]	Recycling rate (RCR_i) [%]	Impacts for the production of virgin material (V_i) [unit/kg]	Impacts for the Disposal (D_i) [unit/kg]	Impacts due to recycling (R_i) [unit/kg]	$m_{recyc,i}$*RCR_i *(V_i+D_i-R_i)	References and details
External cables	copper	0.39	24%	2.03E-03	1.14E-09	2.19E-04	1.69E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
PCB	gold	3.52E-05	25.6%	5.82E+01	1.14E-09	2.22E-04	5.24E-04	primary / secondary gold (ecoinvent); (recycling rate from Meskers et al., 2009)
	silver	2.46E-04	11.5%	1.37E+00	1.14E-09	3.80E-06	3.87E-05	primary / secondary silver (ecoinvent); disposal of metals from (ELCD)
	palladium	7.39E-06	25.6%	6.60E-01	1.14E-09	1.47E-03	1.25E-06	primary / secondary palladium (ecoinvent); disposal of metals from (ELCD)
	copper	6.90E-02	60%	2.03E-03	1.14E-09	2.19E-04	7.49E-05	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Front door	ABS	0.36	94%	1.50E-06	1.05E-08	n.a.	n.a.	primary ABS and plastic disposal from ELCD; no data about ABS recycling;
Motor	copper	0.925	85%	2.03E-03	1.14E-09	2.19E-04	1.42E-03	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
	Steel	1.5	90%	7.15E-08	1.14E-09	0	9.81E-08	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)
Various	aluminium	2.31	91%	1.72E-05	1.14E-09	1.23E-05	1.04E-05	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	Steel	22.82	94%	7.15E-08	1.14E-09	0	1.56E-06	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)
	cast-iron	1.30	60%	1.20E-06	1.14E-09	0	9.40E-07	cast iron primary from (ecoinvent); recycling of cas-iron assumed analogous to steel recycling; disposal of metals from (ELCD)
	Brass	0.07	70%	1.00E-03	1.14E-09	n.a.	n.a.	Brass primary from (ecoinvent);recycling of brass n.a. ; disposal of metals from (ELCD)
	ABS	0.87	74%	1.50E-06	1.05E-08	n.a.	n.a.	primary ABS and plastic disposal from ELCD; no data about ABS recycling;
	PP	0.18	90%	4.62E-08	1.05E-08	n.a.	n.a.	primary PP and plastic disposal from ELCD; no data about PP recycling;
	PS	0.22	83%	4.24E-07	1.05E-08	n.a.	n.a.	Polystyrene production from (plasticeurope); disposal of plastics from (ELCD)

Life Cycle impacts of the product:

A. Impacts due to the production of materials (Σm * $E_{v,n}$) [unit]	4.6E-03	Details: (provided in the text)
B. Impacts due to the manufacturing of the product (M_n) [unit]	1.5E-06	Details: (provided in the text)
C. Impacts due to the use of the product (U_n) [unit]	2.0E-04	Details: (provided in the text)
D. Impacts due to the disposal of materials (Σm * $E_{d,n}$) [unit]	2.5E-06	Details: (provided in the text)
Sum of the impacts (A +B+C+D)	4.8E-03	kg $Sb_{eq.}$
Sum of benefits due to recyclable parts Σ$m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]	0.00224	kg $Sb_{eq.}$
Recyclability Benefit rate (*R'$_{cyc,n}$*) [%]	46.6%	

Table 42 Recyclability Benefit rate of WM1 for various impact categories

	Impact category											
	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl. fossil
Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Sum of benefits	7.3E+01	7.4E-01	2.0E-01	5.8E-06	2.1E-01	4.0E-02	5.4E-02	4.2E+02	3.7E+00	2.5E+00	2.2E-03	3.8E+02
Life cycle impacts	1.2E+03	8.5E+00	2.8E+00	2.3E-04	1.9E+00	3.7E-01	8.6E-01	5.8E+02	7.7E+00	5.2E+00	4.8E-03	1.2E+04
	Recyclability Benefit Rate [%]											
Recyclability Benefit Rate (WM1)	6.3%	8.7%	7.3%	2.5%	11.0%	10.9%	6.3%	72.7%	48.2%	48.3%	46.6%	3.3%

From the analysis of Table 42, it is derived that the EoL treatments of the product allow some generally low benefits for various categories (e.g. GWP, ADP-fossil, Ozone depletion, etc), and relevant benefits in human toxicity, terrestric ecotoxicity, aquatic ecotoxicity and terrestric ecotoxicity and ADP-elements. The further step of the analysis if to couple Recyclability benefit rates results with LCA results in order to:

- identify components that are responsible of large life-cycle impacts,
- identify impact category characterized by higher improvement potential.

Table 42 illustrates the LCA of the WM1 (used as denominator of the RRR benefit rates). Some disaggregated results about the product life-cycle impacts are:

- The use phase dominates the majority of impact categories including: ADP-fossil (82.5%); Acidification (82.9%); GWP (82.4%); Eutrophication (73.7%); ozone layer depletion (93.7%); and marine Eutrophication, particulate matter and photochemical oxidant formation (all around 80%). The use phase is also relevant for other impact categories including human toxicity (18%) and terrestric and aquatic ecotoxicity (about 40%). Low relevance of the use phase for the ADP-element impact category (4%)
- The production of materials dominated instead the ADP-element impact category (95.8%), the human toxicity (81.3%), and it is relevant for the terrestric and aquatic ecotoxicity (about 50%). In particular, the production of the PCB largely influences the ADP-element impact while the production of copper (in the motor) largely affects the ADP-element, the terrestric and aquatic ecotoxicity impacts. Also the production of steel and aluminium are relevant for some impact categories as e.g. aquatic and terrestric ecotoxicity and GWP;
- The manufacturing phase contributes to about 2% of various impact categories.
- The disposal impacts are generally not relevant, except for the Eutrophication (6%) and the terrestric ecotoxicity (5%).

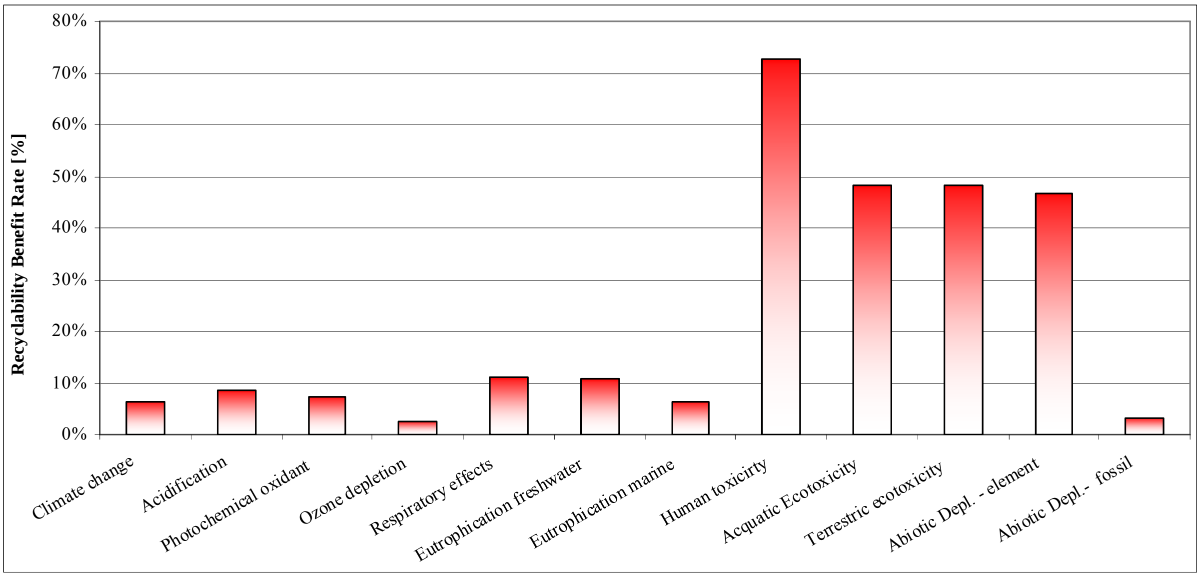

Figure 12 Recyclability Benefit rate of WM1 for various impact categories

Figure 12 above on the different recyclability benefits rates shows instead that the values for the ADP-element category are much lower than the impacts due to the production of the materials[94]. Such low values can be related mainly to loss of relevant materials in the PCB and the motor. Improvement potentials for the Recyclability benefits for the ADP-element are estimated around 50%.

Some relevant improvement potentials (around 10%) are also estimated concerning the human toxicity and the terrestric and aquatic ecotoxicity.

A better design for EoL treatments of PCB and motor (including copper parts) could therefore imply relevant environmental benefits at product level.

6.4.2.4 Energy Recoverability benefit rate

Table 43 illustrates the calculation of the energy recoverability benefit ratio for the indicator "Abiotic depletion fossil".

It results that the Recoverability benefit ratio amounts to: 1.8%. It means that, following the assumption for the EoL of the product, a benefit of 1.8% of the overall energy consumption during the life-cycle of the WM1 can be achieved[95].

[94] The Recyclability benefit rate for the ADP-element impact resulted 47%. On the other side, the production of materials of the WM is responsible of about 96% of the same impact category. It means that about 50% of the life cycle impacts could be potentially recovered. The analysis of the requirements in Section 6.6 will focus on this potential in order to identify if and how this potential benefit could be achieved.

[95] [95] For the calculation it is assumed that plastics in electrical cables are not energy recovered [IEC/TR 62635, 2012]. Recovery rate of epoxy resins in PCBs estimated from IEC/TR 62635 (Korean scenario).

Table 43 Calculation of the Energy Recoverability Benefit rate of WM1

Product Details	
Product	**Mass (m) of the product [kg]**
Washing machine (WM1)	71.744
Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential (fossil)
Unit of measure	MJ

Energy Recoverable material / parts:

Energy Recoverable part	Material	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	Heating Value (HV_i) [MJ/kg]	efficiency for electricity (η_{el})	efficiency for heat (η_{heat})	Impact for electricity (El_n) [unit/MJ]	Impact for heat ($Heat_n$) [unit/MJ]	Impact for incineration ($I_{n,i}$) [unit/kg]	$(m_{recov,i} * RVR_i * HV_i) * (\eta_{el} * El_n + \eta_{heat} * Heat_n) - m_{recov,i} * I_{n,i}$	References and details
Printed circuit board	Epoxy resin	0.07	90%	31	0.3	0.6	1.7	1.09	0.54	2.21	High Heating Values of plastics and wood estimated from various references; impact of electricity (EU-27 power mix) and Heat (EU-27 heat) from ELCD; impact of incineration of wood and plastics from ecoinvent
Porthole frame	ABS	0.36	95%	36	0.3	0.6	1.7	1.09	0.54	14.04	
Chipboard	Wood	2.06	90%	16.7	0.3	0.6	1.7	1.09	0.15	35.43	
EPDM pipes	EPDM	2.22	90%	42	0.3	0.6	1.7	1.09	0.54	95.80	
Remaining ABS components (Various)	ABS	0.87	75%	36	0.3	0.6	1.7	1.09	0.54	26.62	
Polyacryl (PA) (various)	PA	0.02	5%	30.8	0.3	0.6	1.7	1.09	0.54	0.02	
Polymethylmethacrylat (PMMA) (Various)	PMMA	0.003	5%	26.4	0.3	0.6	1.7	1.09	0.54	0.00	
Polypropylen (PP) components (various)	PP	0.18	91%	46	0.3	0.6	1.7	1.09	0.54	8.37	
Polypropylen (PP) with fillers (various)	PP with fillers	8.43	5%	46	0.3	0.6	1.7	1.09	0.54	17.83	
Polystryrene (PS) (Various)	PS	0.22	84%	41	0.3	0.6	1.7	1.09	0.54	8.60	

Life Cycle impacts of the product:

A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]	1935.8	Details:
B. Impacts due to the manufacturing of the product (M_n) [unit]	254.3	Details:
C. Impacts due to the use of the product (U_n) [unit]	9585.7	Details:
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]	33.4	Details:
Sum of the impacts (A +B+C+D)	11,809.2	MJ
Sum of benefits due to energy recoverable parts:	208.94	MJ
Energy Recoverability Benefit rate ($R'_{cov,n}$) [%]	1.8%	

6.4.3 Calculation of the recycled content indices

As discussed in the previous chapter, the analysis of the recycled content indices has been not performed for the WM case-study.

6.4.4 Assessment of the use of hazardous substances in the WM1

The scope of the assessment is the identification of components in the WM that are potentially relevant for their content of potential hazardous substances according to the method illustrated in Report n° 3[96]. The assessment is based on the following steps:

- 'Step 1 – substances considered'. The analysis has been restricted to substances regulated by the RoHS directive.
- 'Step 2 - identification of components embodying the substances. It is highlighted that a detailed BOM of the WM was not available (in particular the detail of content of substances in the electronic components and plastics). The identification has been therefore performed on the basis of information collected at the recycling plants and data from the scientific literature. The following components can be potentially relevant for the analysis:
    - o PCB and capacitors, for the potential content of mercury and cadmium (see Table 35 for some average content) and the content of polychlorobiphenyl.

[96] Report n° 3 - Section 4.3.1.

   - LCD screen, if present, for the potential content of heavy metals (no detailed figures available on the content).

- ‘Step 3 - identification of EoL treatments of potentially relevant components’. According to the EoL scenario set (Table 32), the treatments are:

   - PCB larger of 10 cm^2 are manually disassembled or pre-shredded and sorted by hand-picking. The separated PCBs undergo further treatments for the recovery of some metals, while potentially hazardous substances remains in the residues to be incinerated / landfilled;

   - LCD, smaller than 100 cm^2, if present, are manually disassembled if time for disassembly is lower that a fixed threshold (30 seconds). Otherwise LCD are shredded and partially sorted by hand-picking to be landfilled. No evidences about further treatments for the separation of hazardous substances potentially embedded.

- ‘Step 4 - identification of key components’. According to the previous steps no key component is identified as relevant for the analysis. It is highlighted that PCB and LCD lamps could be potentially relevant but detailed BOMs are necessary for a more comprehensive analysis.

6.4.5 Calculation of the durability indices

The analysis of the durability indices to the WM case-study will be discussed in Report n° 1.

6.5 Analysis of the case-study: WM2

The following sections illustrate the application of methods developed in Report n° 3 for the calculation of the RRR rates and RRR benefit rates.

Table 44 illustrates the EoL scenario applied to the WM2.

Table 44 EoL scenario of WM2

Part	Mass [g]	Conditions	Pre-processing	Further treatment	Typology of part
No parts to be reused	-	-	-	-	-
Capacitors	145	Extracted after shredding (T > 30s)	pre-shredding + handpicking	Landfill / incineration	Part for selective treatment
PCBs (all larger than 10 cm^2)	921	Extracted after shredding (T > 50s)	pre-shredding + handpicking	Recycling	Part for selective treatment
Plastic containing brominated flame retardants (not detected)	-	-	-	-	-
LCD screens (including PCB >10cm2) smaller than 100cm2 without backlighting system	120	dimantled (T < 60 sec)	manual dismantling	Landfill	Part for selective treatment
External Electrical cables	476	No problems detected to disassembly	manual dismantling	Recycling	Part for selective treatment
Internal Electrical cables	476	Not dismantled (T > 10 sec)	shredded	Landfill	Other parts (for material separation)
Electrical motors	2,820	Not dismantled (T > 50 sec)	pre-shredding + handpicking	Recycling	Other parts (for material separation)
Large plastic parts: ABS front door	360	dimantled (T < 30 sec)	manual dismantling	Recycling	Part for selective recycling
Other plastic parts (various)	4,332	-	shredded + mechanical separation	Partial Recyling / Recovery	Other parts (for material separation)
External pipes	2,960	No problems detected to disassembly	manual dismantling	Landfill / Energy recovery	Part difficult to process
Chipboard	2,468	Dismantled (T < 30 sec)	manual dismantling	Landfill / Energy recovery	Part difficult to process
Front door (glass)	1,476	No problems detected to disassembly	manual dismantling	Landfill	Part difficult to process
Bottom counterweights (cast-iron)	28,000	Dismantled (T < 60 sec)	manual dismantling	Recycling	Part difficult to process
Other metal parts (cast-iron, copper, steel,a luminium)	47,528	-	shredded + mechanical separation	Recycling	Other parts (for material separation)
Other materials (cotton mat + unspecified materials)	4,970	-	shredded	landfill	Other parts (for material separation)

6.5.1 Calculation of the RRR indices for the case-study WM2

The following section describes the calculation of the RRR indices for the WM2.

6.5.1.1 Reusability rate

No reusable parts are detected. Reusability rate of the WM2 is: $R_{Use} = 0\ \%$.

6.5.1.2 Recyclability rate

The Recyclability rate is calculated in the following data-sheet. Recyclability rate of the WM2 is: R^*_{cyc} = *77.8* %. This value is in line with recycling targets established by the recast of WEEE directive [European Council, 2012]. However, it is highlighted that the index here discussed focuses on the 'recyclability' as potential at the design stage, while the WEEE Directive refers to target values of recycled WEEE among some macro-categories[97].

Table 45 Calculation of the Recyclability rate of WM2

Product Details					
Product	**Mass (m) of the product [kg]**				
Washing machine (WM2)	97.05				
Parts for selective treatment:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
External cables	Copper and plastics	0.476	24%	1.1E-01	low current cable from IEC 62635
Parts for selective recycling					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Front door frame	ABS	0.36	94%	3.4E-01	IEC 62635
Parts difficult to process:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Chipboard	wood	2.47	0%	0E+00	no data available
Counterweights	cast-iron	28	95%	2.7E+01	IEC 62635 (single recyclable metals)
Rubber pipes	EPDM	2.96	0%	0.0E+00	IEC 62635
Front door	Glass	1.48	0%	0.0E+00	IEC 62635
LCD screen	LCD + PCB	0.12	0%	0.0E+00	IEC 62635 (for LCD)
	ABS	0.23	74%	1.7E-01	IEC 62635
Other parts (for material separation):					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Aluminium components (various)	Aluminium	3.61	91%	3.3E+00	IEC 62635
Steel components (various)	Steel	42.73	94%	4.0E+01	IEC 62635
Motor	Steel	2.00	90%	1.8E+00	Estimation
	Copper	1.03	85%	8.7E-01	
Cast iron components (various)	cast-iron	0.78	60%	4.7E-01	assumed as non magnetic steel (from IEC 62635 from Korean data)
Internal cables	Copper and plastics	0.476	0%	0.0E+00	Estimation
Main PCB	Board (various)	0.321	11.8%	3.8E-02	recycling rate estimated from various references
	PP	0.11	90%	9.9E-02	IEC 62635
Secondary PCB	Board (various)	0.715	11.8%	8.4E-02	recycling rate estimated from various references
	PP	0.20	90%	1.8E-01	IEC 62635
	capacitor	0.030	0%	0.0E+00	IEC 62635
	Aluminium	0.20	91%	1.8E-01	IEC 62635
Remaining ABS components (Various)	ABS	0.84	74%	6.2E-01	IEC 62635
Polyethylene (various)	PE	0.03	90%	2.4E-02	IEC 62635
Polypropylene (PP) components (various)	PP	0.49	90%	4.4E-01	IEC 62635
PP parts with fillers	PP with fillers (including carboran)	2.23	0%	0.0E+00	IEC 62635 (PP with other additives)
Polymethylmethacrylat (PMMA) (Various)	PMMA	0.185	0%	0.0E+00	Other polymers (IEC 62635)
Polyoxymethylen (various)	POM	0.03	0%	0.0E+00	Other polymers (IEC 62635)
Insulation mat	Cotton with phenolic binder	1.62	0%	0.0E+00	Estimation
Other materials	Various	3.35	0%	0.0E+00	no data available
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				**75.48**	
Recyclability rate (*R^* cyc*) [%]		**77.8%**			

[97] It is also highlighted that the targets of the WEEE Directive based on the measured amount of wastes treated in the recycling plants, while the calculation of the recyclability rates are based on the assumed values of recycling/recovery rates of different materials/components as in the IEC/TR 62635 (including also the efficiency of the separation of the materials and their effective losses).

For the calculation it has been assumed that recycling rate of PCB is 11.8% (based on Table 37).

It is possible to observe that the Recyclability of the WM2 is much larger compared to value of WM1. Main reasons for that are:

- The use of cast-iron for counterweights. Being that cast-iron can be separated after by mechanical systems with relatively high recycling rates (from 60% to 95% percent, depending if the component is manually separated) the overall value of the Recyclability rate is very high.

- Compared to WM1, the WM2 case-study has a much lower percentage of plastics. In particular, not recyclable plastics (including PP parts with fillers) are less than 2% in mass of the product.

6.5.1.3 Recoverability rate

The Recyclability rate is calculated in the following data-sheet. It results that the Recyclability rate of the WM2 is: R_{cov} = *83.6%.*

Table 46 Calculation of the Recoverability rate of WM2

Product Details					
Product	Mass (m) of the product [kg]				
Washing machine (WM2)	97.05				
Reusable Parts:					
Part		**Mass ($m_{reuse,i}$) [kg]**	**Evidences for the reuse of the part**		
No reusable parts detected		0			
Parts for selective treatment:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
External cables	Copper and plastics	0.476	24%	1.1E-01	low current cable from IEC 62635
Parts for selective recovery:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Front door frame	ABS	0.36	95%	3.4E-01	IEC 62635
Parts difficult to process:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Chipboard	wood	2.47	90%	2.2E+00	Estimation
Counterweights	cast-iron	28	95%	2.7E+01	IEC 62635 (single recyclable metals)
Rubber pipes	EPDM	2.96	90%	2.7E+00	IEC 62635
Front door	Glass	1.48	0%	0.0E+00	IEC 62635
Other parts (for material separation):					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Aluminium components (various)	Aluminium	3.61	91%	3.3E+00	IEC 62635
Steel components (various)	Steel	42.73	94%	4.0E+01	IEC 62635
Motor	Steel	2	90%	1.8E+00	Estimation
	Copper	1.03	85%	8.7E-01	
Cast iron components (various)	cast-iron	0.78	70%	5.5E-01	IEC 62635
Internal cables	Copper and plastics	0.476	0%	0.0E+00	estimation (from IEC 62635)
Main PCB	Board (various)	0.32	61%	2.0E-01	IEC 62635 (rich board)
	PP	0.11	91%	1.0E-01	IEC 62635
Secondary PCBs	Board (various)	0.72	60%	4.3E-01	IEC 62635 (intermediate board)
	PP	0.20	91%	1.8E-01	IEC 62635
	Various	0.030	0%	0.0E+00	IEC 62635
	Aluminium	0.20	91%	1.8E-01	IEC 62635
LCD screen	LCD + PCB	0.12	0%	0.0E+00	IEC 62635 (for LCD)
	ABS	0.23	75%	1.7E-01	IEC 62635
Remaining ABS components (Various)	ABS	0.84	75%	6.3E-01	IEC 62635
Polyethylene (various)	PE	0.03	91%	2.5E-02	IEC 62635
Polypropylene (PP) components (various)	PP	0.49	91%	4.4E-01	IEC 62635
PP parts with fillers	PP with fillers (including carboran)	2.23	5%	1.1E-01	IEC 62635
Polymethylmethacrylat (PMMA) (Various)	PMMA	0.185	5%	9.3E-03	IEC 62635
Polyoxymethylen (various)	POM	0.03	5%	1.3E-03	IEC 62635
Insulation mat	Cotton with phenolic binder	1.62	0%	0.0E+00	no data available
Other materials	Various	3.35	0%	0.0E+00	no data available
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				**81.09**	
Recoverability rate (*Rcov*) [%]		**83.6%**			

6.5.2 Calculation of the RRR Benefit rates for the case-study WM2

The following sections apply the methods for the calculation of the RRR Benefits rates as introduced and discussed in Report n° 3 – Chapter 2.

6.5.2.1 Life cycle impacts of the WM2

Life-cycle impacts of the WM2 are necessary for the calculation of the RRR benefits ratios. For the calculation of the Life-cycle impacts of the WM2 the following assumptions have been applied:

- Assumption about the production of materials:
  - o Bill of Materials: as in Table in Section 6.3.
  - o Life-Cycle-Inventory data of materials from various references [ecoinvent; ELCD, 2010; PE; BUWAL; PlasticsEurope];
  - o Data about production of LCD screen in the WM are not available;
  - o Impacts of packaging not considered.
- Assumption about the manufacturing phase (as for WM1);
- Assumptions about the use phase (as for WM1)[98]
- Assumptions about the impacts of EoL (as for WM1).

6.5.2.2 Reusability benefit rate

No reusable parts are detected in the case-study. The Reusability benefit rate is therefore 0%.

6.5.2.3 Recyclability benefit rate

Recycling rates of materials are those used for the Recyclability rate index, with the following additional assumptions:

- Recycling rates of copper, gold, silver, platinum and palladium are those introduced in Table 37
- Recycling rates of plastics from PCB are assumed null (thermoset plastics not recyclable).
- Recycling rates of plastics covering frames of PCBs (in ABS and PP) and aluminium heat-sinks of PCBs refer to IEC/TR 62635 (relatively to unsorted shredded materials).

Table 47 illustrates the calculation of the recyclability benefit ratio for the indicator "Abiotic depletion elemental". It results that the Recyclability benefit ratio amounts to: 33.9%. It means that, following the assumption for the EoL of the product, a saving of 33.9% of the life-cycle ADP impact can be achieved.

Table 48 and Figure 13 illustrate the recyclability benefit ratio calculated for other impact categories. In particular, Table 48 illustrates the LCA impacts of the WM2 for the various impact categories and the benefits that can be achieved due to current EoL treatments.

Also in this case it is important to underline that contribution of plastics to recyclability benefit index is not accounted due to missing life-cycle inventory data of recycled plastics. However, it is estimated that their contribution would be negligible for the ADP elemental impact category, but it could more relevant for other impacts categories (as e.g. ADP fossil).

[98] The current analysis mainly focused on impacts of the product in life phases other than use. Therefore, figures about energy consumption during the use phase have been not differentiated for the various products.

Table 47 Calculation of the Recyclability Benefit rate of WM2 for the ADP elements impact category

Product Details								
Product	**Mass (m) of the product [kg]**							
Washing machine (WM2)			97,052					
Impact category for the calculation								
Impact category (n)		Abiotic Depletion Potential elemental (ADP)						
Unit of measure		kg $Sb_{eq.}$						
Recyclable parts:								
Recyclable part	**Material**	**Mass ($m_{recyc,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**Impacts for the production of virgin material (V_i) [unit/kg]**	**Impacts for the Disposal (D_i) [unit/kg]**	**Impacts due to recycling (R_i) [unit/kg]**	**$m_{recyc,i}$*RCR_i*(V_i+D_i-R_i)**	**References and details**
External cables	copper	0.476	24%	2.03E-03	1.14E-09	2.19E-04	2.07E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
PCBs	gold	1.60E-04	25.6%	5.82E+01	1.14E-09	2.22E-04	2.38E-03	primary / secondary gold (ecoinvent);
	silver	8.84E-04	11.5%	1.37E+00	1.14E-09	3.80E-06	1.39E-04	primary / secondary silver (ecoinvent); disposal of metals from (ELCD);
	palladium	5.13E-05	25.6%	6.60E-01	1.14E-09	1.47E-03	8.65E-06	primary / secondary palladium (ecoinvent); disposal of metals from (ELCD);
	copper	2.26E-01	60.0%	2.03E-03	1.14E-09	2.19E-04	2.46E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD);
	Platinum	1.28E-05	25.6%	2.50E+00	1.14E-09	1.47E-03	8.23E-06	primary / secondary platinum (ecoinvent); disposal of metals from (ELCD);
	Aluminium	2.00E-01	91%	1.72E-05	1.14E-09	1.23E-05	9.01E-07	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	PP	3.10E-01	90%	4.62E-08	1.05E-08	n.a.	n.a.	primary PP and plastic disposal from ELCD; no data about PP recycling;
	ABS	2.33E-01	74%	1.50E-06	1.05E-08	n.a.	n.a.	primary ABS and plastic disposal from ELCD; no data about ABS recycling
Front door	ABS	0.36	94%	1.50E-06	1.05E-08	n.a.	n.a.	
Motor	copper	1.027	85%	2.03E-03	1.14E-09	2.19E-04	1.58E-03	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
	Steel	2	90%	7.15E-08	1.14E-09	0	1.31E-07	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)
Counterweights	cast-iron	28	95%	1.20E-06	1.14E-09	0	3.19E-05	cast iron primary from (ecoinvent); recycling of cas-iron assumed analogous to steel recycling; disposal of metals from (ELCD)
Various	cast-iron	0.78	60%	1.20E-06	1.14E-09	0	5.62E-07	
	aluminium	3.61	91%	1.72E-05	1.14E-09	1.23E-05	1.62E-05	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	Steel	42.73	94%	7.15E-08	1.14E-09	0	2.92E-06	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)
	ABS	0.84	74%	1.50E-06	1.05E-08	n.a.	n.a.	primary ABS and plastic disposal from ELCD; no data about ABS recycling;
	PP	0.49	90%	4.62E-08	1.05E-08	n.a.	n.a.	primary PP and plastic disposal from ELCD; no data about PP recycling;
Life Cycle impacts of the product:								
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]		1.3E-02	Details: (provided in the text)					
B. Impacts due to the manufacturing of the product (M_n) [unit]		1.5E-06	Details: (provided in the text)					
C. Impacts due to the use of the product (U_n) [unit]		2.0E-04	Details: (provided in the text)					
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]		2.9E-06	Details: (provided in the text)					
Sum of the impacts (A +B+C+D)		1.4E-02	kg $Sb_{eq.}$					
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]		4.623E-03	kg $Sb_{eq.}$					
Recyclability Benefit rate ($R'_{cyc,n}$) [%]		33.9%						

Table 48 Recyclability Benefit rate of WM2 for various impact categories

	Impact category											
	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl. fossil
Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Sum of benefits	1.4E+02	1.2E+00	3.7E-01	1.0E-05	4.4E-01	8.2E-02	9.3E-02	5.2E+02	6.1E+00	5.4E+00	4.6219E-03	1.3E+03
Life cycle impacts	1.3E+03	9.7E+00	3.1E+00	2.4E-04	2.3E+00	4.4E-01	9.4E-01	7.2E+02	1.2E+01	8.5E+00	1.4E-02	1.2E+04
	Recyclability Benefit Rate [%]											
Recyclability Benefit Rate (WM2)	10.7%	12.5%	12.0%	4.1%	18.9%	18.9%	9.9%	73.0%	50.7%	63.4%	33.9%	10.7%

From the analysis of Table 48, it is derived that the EoL treatments of the product allow some benefits (from 5% to 20%) for various categories, and some relevant benefits for the human toxicity, aquatic ecotoxicity and terrestric ecotoxicity.

Subsequently, the results of the Recyclability benefit rates have been analysed together with LCA results, analogously to what previously done for the WM1 case-study.

Table 48 illustrates the LCA results of the WM2 (used as denominator of the RRR benefit rates). Some disaggregated results about the product life-cycle impacts are:

- The use phase dominates the majority of impact categories including: ADP-fossil (78.1%); Acidification (72.8%); GWP (75.1%); Eutrophication (61.9%); ozone layer depletion (90.3%); and marine Eutrophication, particulate matter and photochemical oxidant formation (all around 70%). The use phase is also relevant for other impact categories including human toxicity (15%) and terrestric and aquatic ecotoxicity (around 25%). Negligible relevance of the use phase for the ADP-element impact category (1%)

- The production of materials dominated instead the ADP-element impact category (98.5%), the human toxicity (84.9%), and it is relevant for the terrestric and aquatic ecotoxicity (about 70%). In particular, the production of the PCB largely influences the ADP-element impact (about 82%) and human toxicity (15%), while the production of copper (in the motor) largely affects the terrestric (26%) and aquatic ecotoxicity (18%) impacts and the ADP-element impact (15%). Also the production of steel and aluminium are relevant for some impact categories as e.g. aquatic and terrestric ecotoxicity and GWP;

- The manufacturing phase contributes to about 2% for some impact categories.

- The disposal impacts are generally not relevant, except for the Eutrophication (10%) and the terrestric ecotoxicity (8%).

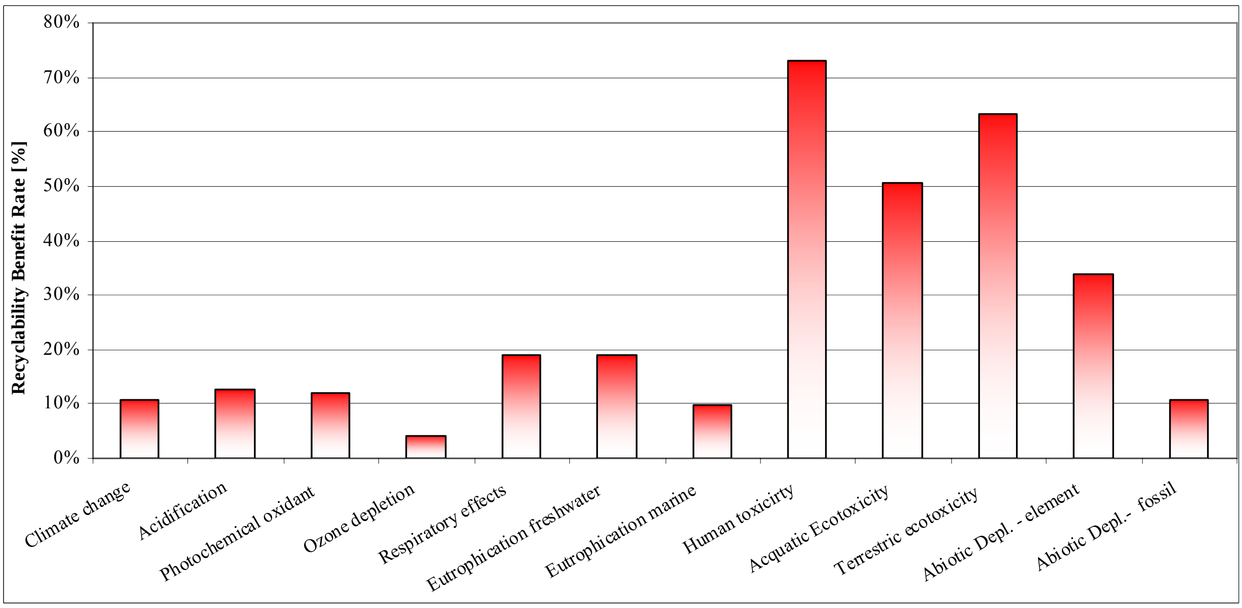

Figure 13 Recyclability Benefit rate of WM2 for various impact categories

The above figures on the different recyclability benefits rates show instead that the values for the ADP-element category are much lower than the impacts due to the production of the materials (even lower than the WM1 case-study, due to larger losses of precious metals from PCBs). It means that, the treatments of the current EoL scenario causes large losses for the ADP-element category. Losses are larger than those observed for the WM1 mainly because of the higher content of relevant and precious metals in the PCBs of WM2. Improvement potentials for the Recyclability benefits for the ADP-element are estimated to be close to 60%.

Some relevant improvement potentials (around 10%) are also estimated concerning the human toxicity and the terrestric and aquatic ecotoxicity.

Also for WM2 a better design for EoL treatments of PCBs and motor (including copper and other relevant materials, as rare earths) could therefore imply relevant environmental benefits at product level.

6.5.2.4 Energy Recoverability benefit rate

Table 49 illustrates the calculation of the energy recoverability benefit ratio for the indicator “Abiotic depletion fossil”.

It results that the Recoverability benefit ratio amounts to: 2%. It means that, following the assumption for the EoL of the product, 2% of the overall energy consumption during the life-cycle of the WM2 could be potentially be recovered[99].

[99] For the calculation it is assumed that plastics in electrical cables are not energy recovered [IEC/TR 62635, 2012]. Recovery rate of epoxy resins in PCBs estimated from IEC/TR 62635 (Korean scenario).

Table 49 Calculation of the Energy Recoverability Benefit rate of WM2

Product Details	
Product	**Mass (m) of the product [kg]**
Washing machine (WM2)	97,052

Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential (fossil)
Unit of measure	MJ

Energy Recoverable material / parts:

Energy Recoverable part	Material	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	Heating Value (HV_i) [MJ/kg]	efficiency for electricity (η_{el})	efficiency for heat (η_{heat})	Impact for electricity (El_n) [unit/MJ]	Impact for heat ($Heat_n$) [unit/MJ]	Impact for incineration ($I_{n,i}$) [unit/kg]	($m_{recov,i}$**RVR$_i$***HV$_i$*)*(η_{el}*El_n + η_{heat}*$Heat_n$) - $m_{recov,i}$*$I_{n,i}$)	References and details
Printed circuit board	Epoxy resin	0.23	90%	31	0.3	0.6	1.7	1.09	0.54	7.26	High Heating Values of plastics and wood estimated from various references; impact of electricity (EU-27 power mix) and Heat (EU-27 heat) from ELCD; impact of incineration of wood and plastics from ecoinvent
Porthole frame	ABS	0.36	95%	36	0.3	0.6	1.7	1.09	0.54	14.04	
Chipboard	Wood	2.47	90%	16.7	0.3	0.6	1.7	1.09	0.15	42.51	
EPDM pipes	EPDM	2.96	90%	42	0.3	0.6	1.7	1.09	0.54	127.74	
Remaining ABS components (Various)	ABS	0.84	75%	36	0.3	0.6	1.7	1.09	0.54	25.64	
Polyethylen (various)	PE	0.03	91%	30.8	0.3	0.6	1.7	1.09	0.54	0.86	
Polymethylmethacryl at (PMMA) (Various)	PMMA	0.185	5%	26.4	0.3	0.6	1.7	1.09	0.54	0.18	
Polypropylen (PP) components (various)	PP	0.49	91%	46	0.3	0.6	1.7	1.09	0.54	23.40	
PP with fillers	PP with fillers and carboran	2.23	5%	46	0.3	0.6	1.7	1.09	0.54	4.71	
Polyoxymethylen (various)	POM	0.03	5%	41	0.3	0.6	1.7	1.09	0.54	0.05	

Life Cycle impacts of the product:

A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]	2722.83	Details:
B. Impacts due to the manufacturing of the product (M_n) [unit]	254.302	Details:
C. Impacts due to the use of the product (U_n) [unit]	9585.68	Details:
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]	43.1053	Details:
Sum of the impacts (A +B+C+D)	12,605.9	MJ
Sum of benefits due to energy	246.38	MJ
Energy Recoverability Benefit rate	2.0%	

6.5.3 Calculation of the recycled content indices

As discussed in the previous chapter, the analysis of the recycled content indices has been not performed for the WM case-study.

6.5.4 Assessment of the use of hazardous substances in the WM2

The analysis of hazardous substances for the WM2 is analogous to the previous WM1 case-study (section 6.4.4).

6.5.5 Calculation of the durability indices

The analysis of the durability indices of the WM case-study will be discussed in Report n° 1.

6.6 Evaluation of potential Ecodesign requirements for the WM product group

The next step of the analysis concerns the identification of product requirements potentially relevant for the WM product group and their qualitative/quantitative assessment.

Information concerning the life cycle impacts of the product has been coupled with results from RRR and RRR Benefits rates, in order to evidence product's parts that were relevant for some impact categories and whose improved recycling could produce relevant benefits at the product level.

Afterwards, possible typologies of requirements[100] have been analyzed to identify possible relevant requirements for the considered product group.

Three requirements have been therefore selected as potentially relevant for the WM case-study:

- improvement of the disassemblability of PCBs.
- improvement of the disassemblability of the LCD screens (when present in the WM).
- improvement of the disassemblability of the motor for the recovery of copper, steel and neodymium (when present).

Some additional potential product's requirements could include:

- Provision of information (concerning key components as PCB and motors).
- Declaration and/or thresholds for the RRR and RRR benefit rates
- Improvement of the product durability (which will be separately identified and discussed in report n° 1).

The potential environmental benefits related to each proposed requirement are discussed in following.

6.6.1 Improvement of the disassemblability of PCBs

a. Identification of the requirement

Based on the LCA of WM case-studies (see sections 6.4.2.3 and 6.5.2.3), PCBs are responsible of relevant life-cycle impacts of the product, especially concerning the ADP-elemental. For example, the PCBs account from about 50% of abiotic resource depletion (ADP elements) (WM1 case-study) to more than 80% (WM2 case-study). The PCBs are also relevant for the human toxicity category (up to 15%).

On the other hands, the analysis of the RRR Benefits rates showed much lower values (from 34% to 47% depending on the considered case-study product). In particular, the detailed analysis of the recycling rates (as part of the Recyclability and the Recyclability Benefit rates) showed that large fraction of copper and precious metal are lost due to the EoL treatments that the products undergo.

The EoL scenario of WM previously introduced pointed out that the manual disassembly of PCBs is not systematically performed[101]. In particular, if the time and efforts to disassembly the PCBs are too high, PCBs are not disassembled. PCBs are instead shredded together with other product's parts and pieces of PCBs are separated afterwards by hand-picking. Scientific study on this EoL treatments have proved that large amounts of relevant materials (including precious metals and some CRMs as palladium and platinum) are lost in dusts and/or in the shredding residues[102].

In discussion with recyclers it emerged that the improvement of the disassembly of the PCBs would stimulate their manual separation and sorting, therefore increasing the recycling rates of the relevant materials and reducing the fraction of copper, precious metals and CRMs lost/landfilled.

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[100] The investigated typologies requirements referred to the results of project EP1 and to requirements already introduced by Ecolabel, GPP of by scientific references, and to suggestions from recyclers.

[101] The WEEE Directive established a selective treatments for PCBs larger than 10 cm^2, although it doe not specify what type of treatments the parts should undergo.

[102] See Section 6.3.1.2 and Report n° 3 – Section 2.2.3 for further details.

It was also observed that several PCBs for WMs are enclosed in some plastic frames (in PP, ABS and ABS/PC). Reason for including this frames are technical, and mostly related to the protections of the PCB from external agents. On the other hands, it has been observed the large difficulty for their manual disassembly. A specific design for disassembly of the frames could sensibly reduce the efforts needed for the extraction of PCBs.

The following box introduced a potential product's requirement for the disassemblability of the PCB.

Potential Requirement: Design for Disassembly of the Printed Circuit Board

Printed Circuit Board larger than 10cm^2 shall be designed in a way that it requires less than 40 seconds[103] to be extracted[104] by professionally trained personnel using the tools usually available to them.

Verification:

Manufacturer shall provide free of charge technical information for disassembly (websites and on demand of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where the printed circuit board is installed in the product, details of the component fastening system, disassembly procedures, tools needed for disassembly)
- The disassembly report should include the time (in seconds) needed for disassembly and the disassembly steps undertook during the testing of the disassembly.

The measurement of the disassembly time could usefully follow a standardized procedure, which would specify the testing method including, for example, the testing environment, how to perform the disassembly, the expertise of the employed personnel, the tools to be used, etc. This procedure should also set the tolerance and sensitivity of the measurements. Some key issues for this procedure are illustrated in Annex 4.

b. Calculation of the environmental benefits at the case-study products level

The next step of the analysis is represented by the assessment of potential environmental benefits related to the application of the proposed requirement to the two considered case-study products (WM1 and WM2).

Two scenarios are therefore compared:

- The first is the 'current' scenario for the considered case-study, in which all the PCBs of the two WMs are sorted/hand-picked only after the preliminary shredding.
- The second is the 'improved' scenario, in which it is assumed that studied WM case-studies would be in line with the previous requirement on disassemblability of PCBs, allowing the manual disassembly of 1 PCB (richness typology: intermediate) from WM1 and two PCBs (richness typology: one rich and one intermediate) from WM2.

[103] This threshold value has been estimated on the basis of survey at three recycling plants and it has been used for the setting of the EoL scenario necessary for the calculation of the RRR rates. This value should be considered as indicative of current practises. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

[104] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.

Table 50 illustrates the recycling rates in the current scenario (based on figures of Table 37 for copper, gold, platinum and palladium) and the higher recycling rates that are estimated to be achieved due to a selective dismantling of PCBs of the two case-study product, once improved the disassemblability of PCBs. The difference between the two scenarios represents the net benefit related to the application of the Ecodesign requirement on disassemblability of PCBs, estimated in term of additional mass of metal recycled per device.

Table 50 Application of the requirement on disassemblability of PCBs to the two case-study WMs

	PCBs (WM1)					PCBs (WM2)				
	copper	silver	gold	palladium	platinum	copper	silver	gold	palladium	platinum
Total mass [g]	6.9E+01	2.5E-01	3.5E-02	7.4E-03	-	2.3E+02	8.8E-01	1.6E-01	5.1E-02	1.3E-02
Recycling rates (current scenario) [%]	60%	11.5%	25.6%	25.6%	25.6%	60%	11.5%	25.6%	25.6%	25.6%
Recycling in the current scenario [g]	41.382	0.028	0.009	0.002		135.884	0.102	0.041	0.013	0.003
Recycling rates (improved scenario) [%]	95%	92%	97%	99%	99%	95%	92%	97%	99%	99%
Recycling in the improved scenario [g]	65.522	0.227	0.034	0.007		215.150	0.813	0.155	0.051	0.013

c. Calculation of the environmental benefits at the product group level

Afterwards, the benefits per single devices are multiplied by the total number of WMs currently produced and that will be wasted at their EoL. It is estimated that in 2012, about 20.7 millions/year of WMs have been sold[105]. It is assumed that 60% of WMs sold belong to the medium-low price typology (WM1) and 40% to the medium-high price typology (WM2)[106].

It is furthermore observed that the adopted EoL scenario is representative of some EoL treatments that WMs undergo[107]. However there is evidence of large recycling facilities where manual dismantling of WM is minimized and waste WMs are treated into big shredders and mechanical devices allows separation of different materials (characterized by higher economic efficiency but also some higher losses for reduced recovery rate of certain materials). Unfortunately, it was not possible to find statistics on the repartition of flows. Therefore, it is estimated that half[108] of waste WMs would undergo this EoL scenario[109]. Therefore it is assessed that the proposed disassemblability requirement will not produce any benefit in this scenario.

In order to consider the above mentioned aspect, it is assumed to halve the estimated benefits. It is therefore assumed that half of currently sold washing machines will be treated by a different EoL scenario and/or already accomplish to the requirement and therefore do not produce any additional benefit.

[105] This figure has been estimated from figures of EU-25 in 2004/05 from the preparatory study for WM [ISIS, 2007]. Figures for EU-27 2012 have been estimated by assuming a 10.7% increase of selling every couple of years.
[106] The subdivision of the overall number of WMs sold between the two case-study product groups is a rough estimation based on the distribution of product's prices, as illustrated in the preparatory study for WM [ISIS, 2007]..
[107] For further details about modeling of alternative EoL scenarios, see Report n° 3 – Section 1.3.2.1.
[108] This flow repartition could obviously be different in the future, considering the dynamic nature of EoL scenarios. However no figures are currently available.
[109] This assumption has been confirmed by EERA (European Electronics Recyclers Association) through a personal communication: the two mentioned scenarios are the two most common ones at the time of the analysis (June 2012).

Table 51 shows the additional masses of recycled metals due to the application of the requirement on the disassemblability of PCBs, and also their relevance in terms of mass flows in the EU27.

It is also noticed that the EoL treatments of WMs are not 'static' but they could change over the time due to market and technological changes. On such purpose, the requirement of disassemblability of PCBs could underpin the manual separation of PCBs otherwise shredded, causing the potential benefits related to such requirement to be higher than what estimated in the following tables.

Table 51 Estimated variation of recycled metals due to the application of the requirement on the disassemblability of the PCB

	copper	silver	gold	palladium	platinum
A. Overall quantities of metals yearly used in the EU27 [10^3 kg/year]	3,525,910	12050	130	720	
B. Overall quantities of metals yearly used in the WMs [10^3 kg/year]	2,735	10.39	1.76	0.52	0.11
C. Overall benefit (additional recycled mass) [10^3 kg/year]	478.67	4.18	0.63	0.19	0.039
Mass fraction (C/A) [%]	0.01%	0.03%	0.48%	0.03%	
Mass fraction (C/B) [%]	17.5%	40.3%	35.7%	36.7%	

Finally Table 52 illustrates the environmental benefits, for different impact categories, related to the additional recycled materials due to the proposed requirement. Values are both in absolute terms and normalized to EU context[110]. It is possible to observe that the largest benefits are related to the human toxicity impact (with a reduction of about 0.7% of the overall EU impacts) and the ADP-element impact category (with a benefit of about 0.05%).

Table 52 Estimated environmental benefits related to the application of the requirement on disassemblability of PCBs (absolute and normalized values)

	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Overall environemntal benefits	1.61E+07	2.92E+06	3.41E+05	1.53E+00	5.45E+05	2.90E+04	5.98E+04	2.25E+08	4.22E+06	1.59E+06	4.34E+04	2.27E+08
Normalized benefit (WM product group)	0.06%	1.6%	0.6%	0.03%	1.3%	0.4%	0.3%	1.7%	2.2%	1.2%	25.1%	0.1%
Normalized benefit (EU27)	0.0003%	0.01%	0.001%	0.000002%	0.01%	0.008%	0.001%	0.7%	0.001%	0.003%	0.05%	0.001%

6.6.2 Improvement of the disassemblability of LCD screens in WMs

a. Identification of the requirement

According to the analysis of the selected case-studies, the amount of electronic parts in WMs is increasing, especially for WMs technologically more advanced. The increased number, complexity and richness of PCBs have been already discussed. Furthermore, some new additional components, as LCD screen, are currently introduced into new WMs, generally embodied to some PCB or other electronic components.

110 Normalization is here referred to the overall environmental impacts of the EU-27 for all the economic sectors. Normalization factor those of Table 11, used for the "high level analysis of the impacts of materials" in Chapter 1.

WMs currently treated in the recycling plants do not currently contain LCD screens but it is expected that in the next future newly developed WMs will reach their EoL.

The WEEE directive sets no requirements about the separation of such LCD in WMs (their dimension is below the threshold of 100 cm^2, generally variable between 25 cm^2 and 60 cm^2, without backlight systems).

All the interviewed recyclers agreed that LCDs in WMs have to be preventively extracted before WM shredding because potentially contaminating other recyclable fractions, as PCBs sorted after pre-shredding by hand-picking or mechanical systems, causing further downcycling of recyclable resources.

Furthermore, the LCD screens can embed some relevant materials (in particular indium) potentially recoverable. However, few details about content of indium in WM's LCDs are currently available. Further detail on the BoM of LCD screens is necessary to assess potential relevant elements and potential contaminants for other recyclable resources.

It is therefore suggested an additional potential requirements on disassemblability of parts containing LCD, as a further specification of the previous requirements on disassemblability of PCBs.

Potential Requirement: Design for Disassembly of the electronic parts with LCD screens

Electronic parts of the WM with LCD screen shall be designed in a way that these can be extracted[111] in less than 30 seconds[112] by professionally trained personnel using the tools usually available to them.

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on website and on demand of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes on where the LCD screen/s and annexed printed circuit board/s are installed in the product, details of the component fastening system, disassembly procedures, tools needed for disassembly)
- The disassembly report should include the time (in seconds) needed for disassembly and the disassembly steps undertook during the testing of the disassembly.

A standardised procedure for the measurement of the disassembly time should be set in analogy to what discussed for the requirement on disassemblability of PCBs (see section 6.6.1 and Annex 4 for further details).

[111] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.

[112] In the survey of recycling plant it has been not possible to observe the recycling of WMs with LCD screen. However, it is assumed that the time for disassembly LCDs (or PCBs enclosing LCD screen) should be more restrictive than the threshold set for the previous requirement on disassemblability, also considering that LCDs are installed in the external framework of the WM and therefore easier to be accessed and dismantled. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

b. Calculation of the environmental benefits at the product group level

A quantitative assessment of benefits relative to the above possible requirement was not possible. It would only be possible if the following data were available:

- data about current EoL treatments of WMs embodying LCD screens
- detailed information about composition of LCD screens in WMs
- information on how LCD waste could contaminate other parts and lowering their recyclability (downcycling).

Further analysis is recommended on this topic. In any case, requirement on disassemblability of parts with LCD screen could contribute to simplify and improve EoL treatments of future WMs by reducing risks of contamination of recyclable parts.

6.6.3 Improvement of the disassemblability of motors

a. Identification of the requirement

Motors represent one of the key parts of washing machine. Mostly due to the large amount of copper, motors are responsible of large life-cycle impacts (e.g. around 65%-70% of Human toxicity potential, 25%-50% of Terrestric ecotoxicity potential and 15%-40% of the ADP-elemental). Motors are also economically one of the most valuable parts for recycling.

Motors are sometimes preventively manually disassembled when time for its separation is reasonably low (assumed lower than 50sec in the previous EoL scenario). Otherwise, WMs are shredded and motors are afterwards separated (by hand-picking or further mechanical separation) which is a process that yield lower recycling rates.

Indeed, studies in the literature evidenced that shredded motors imply more difficulties during the next treatments for separation of metals, with larger losses (see for example [Castro et al., 2004]). Furthermore, avoiding pre-shredding could reduce the contamination among metals, reducing the risk that some copper fractions could contaminate steel batch. However, detailed figures about such losses are not available.

Furthermore, although copper and steels can be partially separated from pre-shredded motors, other elements, including rare earths, could not. For the recovery of such elements, a selective dismantling of motor and further extraction of magnets would be necessary. For example, neodymium and other rare earth contained in some motors (magnets for high efficiency devices) could be only recovered after a selective disassembly[113]. Neodymium represents, among rare earths, one of the most used in terms of overall flows, and particularly relevant for some emerging technologies including permanent magnets (with high energy efficiency) and laser technology [EC, 2010].

Furthermore, as evidenced in some studies in the scientific literature "the rare earth recycling should be addressed by specific requirements, e.g. the obligation for dismantling of selected rare earth containing components" [Schüler et al., 2011].

A potential disassembly requirement for motors of WMs is therefore illustrated.

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[113] For further details about the content and the potential recycling of neodymium, see Section 6.3.1.3.

Potential Requirement: Design for Disassembly of the WM's motors

Motors of WM shall be designed in a way that its extraction[114] requires less than 50 seconds[115] by professionally trained personnel using the tools usually available to them.

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on the manufacturer's website and on demand of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes on where the motor and where is installed in the product, details of the component fastening system, disassembly procedures, tools needed for disassembly)
- The disassembly report should include the time (in seconds) needed for disassembly and the disassembly steps undertook during the testing of the disassembly.

A standardised procedure for the measurement of the disassembly time should be set in analogy to what discussed for the requirement on disassemblability of PCBs (see section 6.6.1 and Annex 4 for further details).

b. Calculation of the environmental benefits at the case-study products level

For the assessment of potential additional environmental benefits related to the application of the requirement to the considered case-studies (WM1 and WM2), two scenarios are compared:

- The first is the 'current' scenario for the considered case-studies, in which the motors are assumed to be sorted (hand-picking or mechanical separation) after a preliminary shredding.
- The second is an 'improved' scenario, in which it is assumed that motors, being in line with the previous requirement on disassemblability, could be preventively disassembled and addressed to further recycling treatments.

For the calculation of the environmental benefits, it is further assumed that:

- Neodymium, praseodymium and other rare earth are only contained in magnets of high efficiency motors (case-study WM2) and they can be separated by other motor parts, once motors are disassembled.
- It is conservatively[116] assumed that, thanks to the proposed disassemblability requirement, 50% of rare earths in magnets could be selectively separated for recycling. This figure is based also on the assumption that, in the next future, a recycling route for rare earths would be established and economically profitable.

[114] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.

[115] This threshold value has been estimated on the basis of survey at three recycling plants and it has been used for the setting of the EoL scenario necessary for the calculation of the RRR rates. Compared to the threshold for the disassemblability of the PCBs, it is here assumed a larger time frame, also considering that motors are generally less accessible to be dismantled. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

[116] Although some experimental plants achieved neodymium recycling rates from 82% to 99% [Schüler et al., 2011], no figures are available concerning recycling rates in large scale plants.

Due to the setting of the previous requirements and the above assumptions, the following additional masses of recycled materials are conservatively estimated for the two considered WMs (Table 53).

Table 53 Estimated benefit, in term of additional recycled masses, due to the application of the requirement on motor disassemblability, at the case-study products level

	Content of metals in the motor [g/WM]		Additional masses of recycled metals [g/WM]	
	WM1	WM2	WM1	WM2
Copper	925	1,027	46.3	51.4
Steel	1500	1935	75.0	96.8
Neodymium	-	40	-	20
Praseodymium	-	10	-	5
Dysprosium	-	10	-	5
Terbium	-	5	-	2.5

c. Calculation of the environmental benefits at the product group level

The next step of the analysis is the calculation of the environmental at the product group level. The estimated additional masses of recycled materials per device have been multiplied by the overall number of WMs currently produced and that will be wasted at their EoL (values illustrated in section 6.6.1).

Analogously to the analysis the requirement for the disassemblability of PCB, it is assumed that only 50% of WMs will beneficiate of such requirement[117]. The estimated figures of overall amount of recycled rare earths are therefore halved.

The overall masses of additional recycled materials are estimated in Table 54. The table also compares the additional quantities of recycled materials to the overall yearly flows of materials in the EU27[118]. It is possible to observe that the requirement could allow recycling a relevant amount of the yearly overall flows of neodymium (around 0.8%). Also in this case, it is noticed that the EoL treatments of WMs are not ‘static’ but they could change over the time due to market and technological changes. On such purpose, the requirement of disassemblability of motors could underpin the manual separation of motors otherwise shredded, causing the potential benefits related to such requirement to be higher than what estimated in the following tables.

[117] This assumption implies that 50% of WMs will undergo a different EoL scenario (largely based on shredding), which would not have benefit from the proposed requirement.

[118] Yearly flows of steel and copper refer to the high level environmental analysis (in Chapter 1). Concerning the flows of neodymium, figures from the “Critical raw materials for the EU” report have been considered [EC, 2010]. No figures instead available for praseodymium, dysprosium and terbium.

Table 54 Estimated benefit, in term of additional recycled masses, due to the application of the requirement on motor disassembly, at product group level

	A. Overall quantities of metals yearly used in EU27 [10^3 kg / year]	B. Overall quantities of metals used for WMs [10^3 kg / year]	C. Benefits in terms of additional recycled mass [10^3 kg / year]	Fraction (C/A) [%]	Fraction (C/B) [%]
Copper	3,525,913 (*)	20,017	500.4	0.01%	2.5%
Steel	79,926,821 (*)	34,695	867.4	0.001%	2.5%
Neodymium	16,800 (**)	331.6	82.9	0.8%	25%
Praseodymium		82.9	20.7		25%
Dysprosium		82.9	20.7		25%
Terbium		41.5	10.4		25%

(*) from the high level environmental analysis (chapter 1); (**) flows of Neodymium in 2006 (from [EC, 2010])

To assess of the environmental benefits related to these additional recycled masses, the following assumptions are introduced:

- Impacts for the production of primary Dysprosium and Terbium are assimilated to those of Neodymium
- Impacts due to the recycling of rare earths are missing in the literature. For the calculation of the benefits it is roughly estimated that the impacts for the recycled rare earths amount to 20% of the primary production.

Environmental benefits related to additional recycled masses are shown in Table 55. Values are both in absolute terms and normalized to EU context[119]. It is possible to observe that the largest benefits are related to the human toxicity impact (mostly related to the additional recycling of copper).

It is highlighted that estimated benefits are affected by hypotheses and uncertainties already underlined concerning the high level environmental assessment in Chapter 1.

Table 55 Estimated environmental benefits related to the additional recycled masses, due to the application of the requirement on motor disassembly (absolute and normalized values)

	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Overall environemntal benefits	6.35E+06	2.92E+05	5.06E+04	8.71E-01	8.06E+04	9.26E+03	1.38E+04	2.29E+08	1.09E+06	1.11E+06	9.41E+02	8.71E+07
Normalized benefit (WM product group)	0.03%	0.2%	0.08%	0.02%	0.2%	0.1%	0.07%	1.7%	0.6%	0.8%	0.5%	0.04%
Normalized benefit (EU27)	0.0001%	0.001%	0.0002%	0.000001%	0.001%	0.003%	0.0002%	0.7%	0.0002%	0.002%	0.001%	0.0003%

6.6.4 Discussion of other potential ecodesign requirements

6.6.4.1 Provision of information

Some additional requirements could regard the provision of information regarding some key components (e.g. PCBs and the motors) concerning, for example, their composition, the location and content of some elements (e.g. rare earths or other critical raw materials).

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119 Normalization is here referred to the overall environmental impacts of the EU-27 for all the economic sectors. Normalization factor those of Table 11, used for the "high level analysis of the impacts of materials" in Chapter 1.

According to the experience of some recyclers in Europe, some problems currently hamper the technological development of plant for the recycling of rare earths and other critical raw materials, including:

- It is not known quantities of critical materials in product, their chemical status, and the content of other substances that could interfere with the recycling;
- Experiences in traditional mining and refining industry is generally not applicable, being that critical raw materials in product's parts are in forms not present in nature (complex mixtures of different metals with plastics and other chemical compounds)
- it is not clear yet if and how recycled materials would be suitable for new manufacturing, nor the quality requirements of input materials by manufacturing companies (e.g. physical/chemical status of input materials, level of purity, etc.)
- Price fluctuations can interfere with recycling activities especially (high risk of investment for development of new plants).

As suggested by recyclers, possible actions to underpin the research could include:

- to collect information about the content of critical raw materials in products and their chemical composition, and the presence of mixture of other chemicals compounds that could interfere with the recycling
- precise estimations of flows of critical raw materials (current and future) and their demand over the time
- survey of manufacturers to specify the technical requirements that input materials should comply with (e.g. compounds needed, physical/chemical status, level of purity, etc.)

Following the above considerations, it is suggested that, a first step to underpin the recycling of rare earth and other CRMs, is significantly improved by the detailed knowledge of the content of critical materials in EEE. A product requirement could therefore focus on the declaration of the content of CRM.

Potential Requirement: Declaration of the content of Rare Earths in WM's motors

Manufacturer should declare the content of rare earths (typology and amount in grams) in the motor of WM.

Verification:

Manufacturer shall provide a declaration to the market surveillance authority accompanied, on request, by laboratory tests proving the declared quantity.

Other similar requirements could be set for other WM's components as e.g.:

- The content of precious metals and CRMs in the PCBs
- The content of CRMs (when present) in other product's parts (as e.g. tantalum in capacitors).

For the enforcement of such declarative requirements some additional guidance and standards on the measurement should be set, including the testing methods for the measurement of the content of the substances to be declared and how this information should be communicated.

The requirement of declaration of rare earths and other CRMs in the product's parts can contribute significantly to the development of European databases for CRMs in products. Recyclers should have access to such databases in order to proactively develop/improve technologies for the recycling of CRMs.

Finally, additional potential requirements could establish the provision of information to recyclers concerning the EoL treatments of the products (of its parts). This would be in line also with the prescriptions of the recast of WEEE Directive[120] in articles 4 and 15 [European Council, 2012]. Also in this case, additional guidance about data to be provided and the data format should be defined. On such purpose, involvement of manufacturers and recyclers is necessary.

6.6.4.2 Declaration and/or thresholds for the RRR and RRR Benefit rates

As discussed in the EP1 and in Chapter 3 of the present report, possible Ecodesign requirements could be based on the declaration (or thresholds) of the RRR and RRR Benefits rates.

Potential benefits related to the application of these declarative requirements (jointly with basic input information for their calculation) could be:

- to induce manufacturer at including EoL considerations already at the design stage of the product
- to communicate to the users the indices. Such information could be used for the comparison of product with different EoL performances
- to communicate to the European Commission about the product's development and to identify potential benchmarks in the market.

Potential benefits related to the application of thresholds could be:

- to induce manufacturer at including EoL considerations already at the design stage of the product;
- to induce manufacturer at redesign the product in order to achieve the established thresholds, by undergoing different strategies (including e.g. the improvement of the disassemblability of some components, the use of more recyclable materials, the reduction of the use materials responsible of high environmental impacts);
- to improve the EoL treatments at the recycling plants.

It is important to underline that declarative requirements could be preparatory to the setting of potential threshold requirements.

It is also highlighted that the calculation of the RRR rates could refer to some particular materials in the product (for example the calculation of Recyclability rate restricted to only the polymers in the product or restricted to one or more CRMs).

Analogously the RRR Benefit rates should be calculated for one (or more) selected impact category. The selection of the target category should reflect the priority of decision makers.

The following box illustrates an example of a potential requirement for the Recyclability Benefit rate.

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[120] For further details , see Report n° 3 – Section 4.2.2.

Potential Requirement: Declaration of the Recyclability Benefit rate for the impact category "X"[121]

Manufacturer should declare the value of the Recyclability Benefit ratio of the product[122].

Verification:

Self declaration of the manufacturer, supported by technical documentation (to be provided to the market surveillance authority on request), including:

- Bill of materials of the product, including information of disassembly of key components (as foreseen in the EoL scenario for WM)

For the calculation of the Recyclability Benefit rate life-cycle data of the products are needed. Some potential uncertainties and difficulties related to the enforcement and verification of this potential requirement should be considered including:

- the availability of comprehensive and consistent data about the recycling/recovery rates of materials and product's components (the IEC/TR 62635 includes a preliminary set of relevant data, but this should be enlarged, updated and, when needed, referred to the European scenario)
- the availability of representative and consistent life-cycle inventory data about the production of virgin and recycled materials.

On such purpose, European life-cycle tools and inventory databases could be developed to guide and simplify the calculation and verification processes.

6.6.5 Comparison of potential environmental benefits

In order to assess the relevance of potential requirements previously discussed, previous figures concerning the estimated benefits have been compared to the estimated benefits that derive from the ecodesign implementing measures for the "Washing Machine" product group already adopted by the EU [EC 2010c].

According to estimations, the implementing measures will grant the yearly saving of 1.5 TWh (end-use electricity in 2020)[123]. Life cycle benefits related to this amount of saving have been calculated according to average life-cycle inventory of average 1 kWh of electricity in the EU27 [ELCD, 2010].

The benefits of this EU implementing measures for washing machines have been afterwards compared with estimated benefits related to the potential requirements on resource efficiency for "WMs" (improved disassemblability of PCBs and motor) previously discussed. Results are illustrated in Table 56.

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[121] The requirements could be set to one or more of the impact categories analyzed in this project, as well as to other potential life-cycle impact categories.

[122] The calculation has to be based on the EoL scenario set in the present Chapter and on the guidance documents illustrated in Report n° 3

[123] European Commission. DG Enterprise and Industry website (http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm; access September 2012)

Table 56 Comparison of the environmental benefits related to the adoption of Ecodesign implementing measures on WM with potential requirements on resource efficiency

A. Total potential benefits due to 2 potential requirements on resource efficiency											
Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutroph. freshwater	Eutroph. marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
2.2E+07	3.2E+06	3.9E+05	2.4E+00	6.3E+05	3.8E+04	7.4E+04	4.5E+08	5.3E+06	2.7E+06	4.4E+04	3.1E+08
B. Total life-cycle benefits related to requirements on resource efficiency of WM (1.5 TWh of electricity saved)											
Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutroph. freshwater	Eutroph. marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
8.9E+08	6.8E+06	2.0E+06	2.2E+02	1.5E+06	2.2E+05	6.2E+05	7.6E+07	2.5E+06	1.2E+06	6.0E+01	9.1E+09
Ratio (A / B) [%]											
2.5%	47.2%	19.2%	1.1%	42.4%	17.1%	11.8%	595%	215%	226%	74325%	3.5%

It is possible to observe that the benefits generally range between 2.5% and 3.5% of benefits of implementing measures for GWP and GER respectively. More relevant ratios (from 11.8% to 47.2%) are estimated for several impact categories. Benefits related to the Human toxicity, Ecotoxicity and “Abiotic Depletion element” impacts are higher for the potential requirements on resource efficiency due to the low incidence of electricity savings for these impact categories.

6.7 Summary and conclusions on the case-study analysis

Results of the assessments

The application of the project’s methods to two case studies based on data communicated from manufacturers brought the following results:

Main considerations concerning the assessment of the WM case-study are:

- The calculation of the RRR Benefits rates (including the calculation of the life-cycle impacts) of the two case-studies has been performed. The analysis showed that the manufacturing of some components is relevant for some impact categories. For example the manufacturing of PCBs dominates the ADP-element impact category, and it is relevant for others (e.g. human toxicity). The content of copper in the motor is very relevant for the terrestric and aquatic ecotoxicity. Finally also steel, aluminium and cast-iron (for WM2) are relevant for several impacts categories (e.g. GWP, human toxicity and photochemical oxidants).
- Afterwards, RRR and RRR Benefits rates have been calculated. It has been observed that:
    - Recyclability index is dominated by large mass components (counterweight). Furthermore, data about the recycling rate of concrete from the WMs are uncertain
    - Reusability and energy recoverability are not relevant for the case-study
    - Recyclability Benefits rates is over 30% for ADP-elements and over 50% for human toxicity, aquatic and terrestric ecotoxicity.

Identified products "hot spots"

Based on the previous results, the following conclusions have been drafted:

- It has been observed some relevant losses of copper and precious metals in the PCBs and some losses of metals (copper, steel and rare earths) in the motor. In particular, rare earths (mainly neodymium) can be embodied in the motors of some high performing devices. These substances are currently lost in recycled steel. There are evidences that these substances could be partially recovered. However, these have to be manually separated from steels flows (not separable by magnetic systems).

- Finally, new WMs introduced in the market embody some LCD screens. All the interviewed recyclers agreed that LCDs in WMs have to be preventively extracted because potentially contaminating other fractions (for example PCBs without LCD) causing a potential downcycling of recyclable resources.

Potential products requirements and associated benefits

Based on the previous analysis, three products requirements potentially relevant have been identified:

- improved disassemblability of PCBs. This would allow a large amount of PCBs to be preventively manually dismantled (instead of being shredded) with higher recycling rates for copper, gold, silver, and PGMs.

- improved disassemblability of motors. This would allow a larger recycling rate (+5%) of embodied metals (steel and copper). Furthermore, this requirement would be essential for the separation of neodymium magnets (when embodied), once commercial recycling routes of rare earth would be established.

- improved disassemblability of LCD screen. This would allow an easier separation of the LCD reducing the risks of contamination of other recyclable parts.

Such requirements could produce the following potential environmental benefits:

- improved disassemblability of PCBs: this would contribute to increase the amount of PCBs preventively separated by unsorted waste flows, with larger recovery of some relevant materials (including copper, gold, silver and platinum group metals). Some relevant additional masses of such metals could be recovered (ranging from 15% to 40% of the uses of these elements into WMs in the EU). It is furthermore estimated that this requirements would allow a reduction of 0.7% of the human toxicity impact for the EU27 and a 0.05% reduction of the ADP-element impact. It is here highlighter that the presented normalized values concerns EU27 (including all the productive sectors). However, the normalization could be different, focusing for example on the specific product group (washing machines) or some product groups (e.g. ErP).

- improved disassemblability of motors: this would contribute to reduce the losses of materials during the recycling treatments (quantified into the additional recycling of about 5% of copper and steel embodied in the WMs). Furthermore, this requirement would be necessary to allow the recycling of some critical raw materials used in motors (e.g. various rare earths present in high efficiency motors)[124, 125]. This requirement could be also complemented by some declarative requirements, including the provision of the information regarding the content and location of the rare earths in the motor. It is estimated that this requirement would allow a reduction of 0.7% of the human toxicity impact for the EU27.

- improved disassemblability of LCD screens in WMs: it is expected that LCD screen will be more and more embodied in future devices. All the interviewed recyclers agreed that LCD screen should be preventively manually extracted to avoid contamination of other recyclable fractions and their further downcycling. However data about possible treatments of LCD in WMs and potential effects on other recyclable fractions are not available[126]. Although it was not possible a quantitative assessment of the potential environmental benefits, this requirements as been introduced and discussed as potentially relevant for future waste flows.

[124] It is for example estimated that rare earths in high efficiency WMs amount to around 3% of the overall uses of neodymium in the EU. Thanks to the proposed requirement on disassemblability of the motor, about 0.8% could be recycled.
[125] It is highlighted that neodymium in motors is current not recycled. Only some experimental plants for the recycling of neodymium and other rare earths been developed.
[126] The survey of recyclers showed that WMs currently recycled do not embody LCD screens.

7. Case-study: LCD-TV

7.1 Introduction

The following sections apply the methods for the calculation of the RRR ratios, and RRR Benefit ratios and for the assessment of the use of hazardous substances (as introduced and discussed in Report n° 3) to a case-study LCD-TV [127]. Afterwards, the method for the identification and assessment of potentially relevant requirements (Chapter 4) is applied.

7.2 Definition of the End-of-Life scenario of LCD-TV

The first step for the calculation of the RRR indices is the definition of the 'EoL scenario'. According to the guidance documents set in Report n° 3 – Section 1.3.2, product's parts have to be subdivided in the following groups: reusable parts; parts for selective treatments; parts for selective recycling; parts difficult to process; other parts (for material separation).

The EoL scenario has been defined on the basis of the typical treatments observed in 3 recycling plants and on the basis of case-studies described in the scientific literature (see for example [Kim et al., 2009; Salhofer et al., 20111]). In particular it has been observed in the very large majority of plants that the LCD-TVs are manually dismantled to separate components potentially dangerous (due to the content of hazardous substances) and recyclable parts.

The EoL treatments of LCD-TV generally include:

- the disassembly of external cables and of front / back covers;
- the disassembly of internal frames;
- the disassembly of main PCBs and internal cables;
- the removal and further dismantling of the LCD screen (including the separation of frames, plastic boards and sheets, and secondary PCBs)
- the disassembly of the backlight system;
- the disassembly and sorting of some additional parts (e.g. large homogeneous plastic parts)
- the further disassembly of other components (e.g. speakers, fans, if any).

[127] The analysis of recycled content has been not applied here because already illustrated for the imaging equipment case-study.

According to communications from recyclers[128], association of recyclers and take back schemes, the representative EoL scenario of LCD TV in the EU considered for this case study is currently based on the full manual disassembly (Figure 14)[129].

Figure 14 Scheme of the EoL treatments for the LCD TV

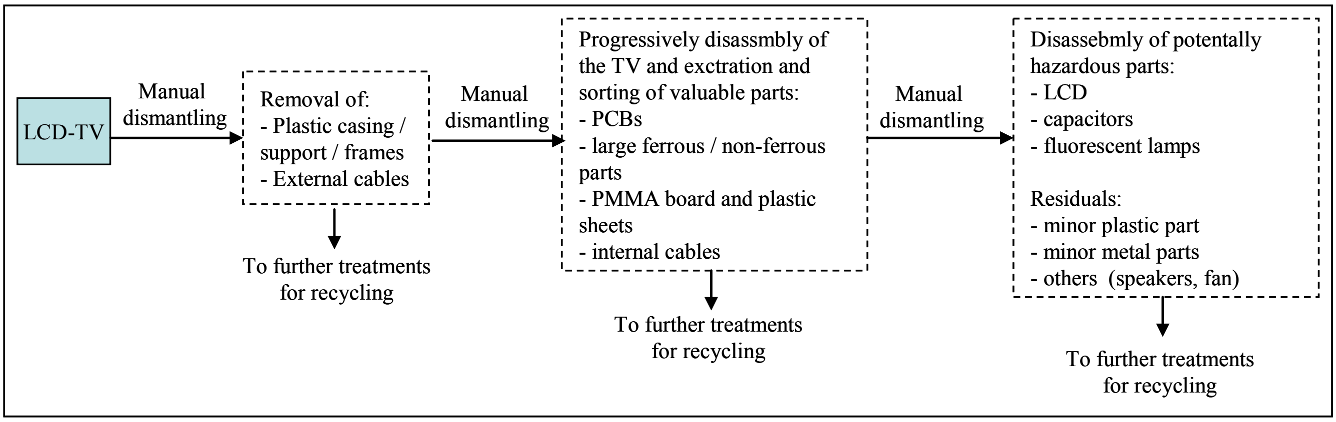

Figure 15 shows an example of composition and structure of an LCD [Kim et al., 2009]. In particular "the manual removal of the backlight system has to be done very careful in order to avoid health hazards to the worker from breaking lamps. In a similar way is the shredding insufficient due to the uncontrolled Hg emissions" [IZM, 2007].

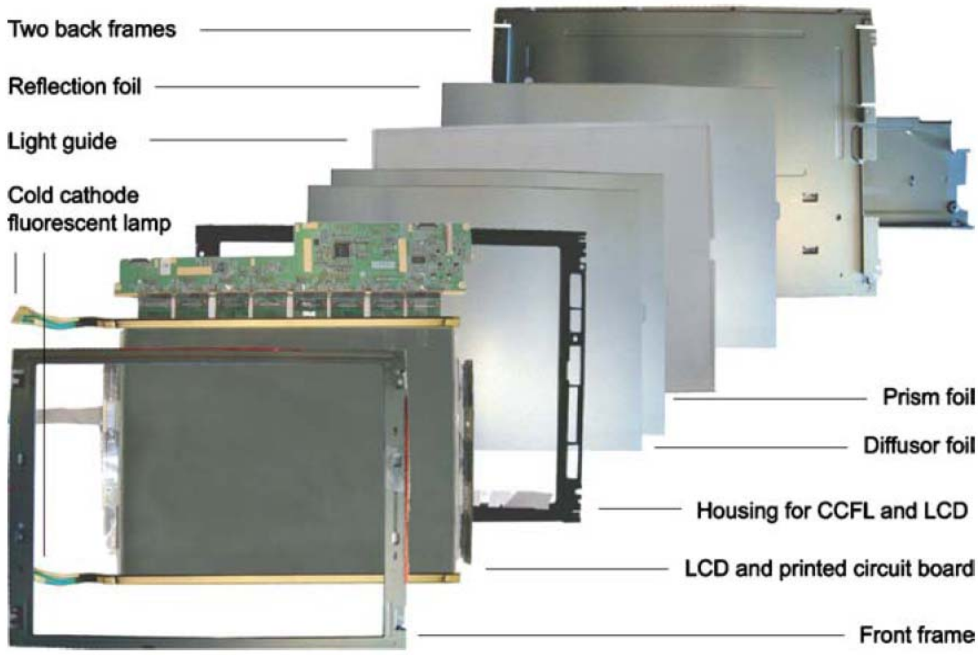

Figure 15 Exemplary structure of an LCD screen [Kim et al., 2009]

[128] The study has been mostly based on data from pre-treatment facilities. However some data from final recyclers have been collected directly or indirectly (thanks to information on the final treatments of materials from pre-treatments facilities or association of recyclers).

[129] This assumption has been confirmed by EERA (European Electronics Recyclers Association) through a personal communication: the full manual dismantling is, at the time of the study (June 2012), treating the majority of the flow of EoL LCD-TV. However, changes in the EoL scenarios are possible in the next future

The following Table illustrates the EoL considered scenario for the LCD-TV.

Table 57 EoL scenario of LCD TV

Part	Conditions	Pre-processing	Further treatment
Parts to be re-used (if any)	- parts can be dismantled in a non-destructive way; - commercial reuse/refurbishment systems established	manual dismantling	Reuse
Fluorescent lamps	Has to be carefully estracted to avoid breackage and release of hazarodus substances	manual dismantling	Recycling (experimental plants - few data available)
LCD screen	Has to be extracted if surface > 100 cm^2	manual dismantling	Landfill
	Otherwise	manual dismantling or mechanical separation	Landfill
PCB (larger than 10 cm^2)	Has to be extracted	manual dismantling	Recycling
PCB (smaller than 10 cm^2) and film connectors	if rich (based on judgment of the worker) and easy to disassembly (T < 120 sec)	manual dismantling	Recycling
	otherwise	manual dismantling and/or mechanical separation	Recycling
Capacitors	Has to be extracted if containing Polychlorobiphenyl or if diameter larger than 2.5 cm	manual dismantling	Landfill / incineration
	otherwise	shredded together with other parts	Landfill / incineration
Plastic containing brominated flame retardants	Has to be separated	Shredding + density separation	Landfill / Recovery
External electrical cables	Has to be extracted (no specific problems detected)	manual dismantling and sorting	Recycling
Internal Electrical cables	Separated during dismantling of other compontents (no specific problems observed)	manual dismantling	Recycling
Large plastic parts: front / back covers (ABS / PP / PS)	- if larger than 200g - if easy to be identified (marked in visible way); - if commercial recycling route established	manual dismantling (and sorted separately from other plastics)	Recycling
	Otherwise	manual dismantling + usorted shredding with other plastics	Recycling
PMMA board	If larger than 200 g	manual dismantling (and sorted separately from other plastics)	Recycling
	Otherwise	manual dismantling + usorted shredding with other plastics	Recycling
Plastic foils (unspecified)	If commercial recycling route established	manual dismantling (and sorted separately from other plastics)	Recycling
	Otherwise	manual dismantling + usorted shredding with other plastics	Recycling
Other plastic parts	-	manual dismantling + usorted shredding	Partial recycling / Energy recovery
Metal parts (ferrous)	- if larger than 50g - if identified (e.g. by magnets)	manual dismantling	Recycling
	Otherwise	manual dismantling and shredded with other metals	Recycling
Metal parts (non-ferrous)	Otherwise	manual dismantling + mechanical separation	Recycling
Speakers		manual dismantling and shredded with ferrous parts	Recycling
Other parts (e.g. Fans) if any		manual dismantling + shredded with plastics	Partial recycling / Energy recovery

It was also identified that some plants have been developed in Europe for the mechanical treatments of LCD, mostly at the testing level. However, these plants are not widespread and little information on performances is still available on them [EMPA, 2011]. For such reasons mechanical treatment of LCD will be not considered in the current EoL scenario. Possible future scenarios (see dynamic nature of scenarios) will be discussed in the following sections concerning the setting of potential ecodesign requirements.

Finally the time for disassembly of the LCD-TV is relevant information. The time depends on various factors including the dimension of the TV and the complexity of the fastening system (e.g. number and typologies of screws and bolts used). It has been measured for 5 LCD-TV sets that the time for fully disassembly a TV of 20'' to 30'' varies from 5 minutes to 9 minutes[130]. Furthermore it is noticed that the LCD screens and the fluorescent lamps are the two most 'nested' components. Their disassembly requires almost all the other parts to be separated first.

The following sections discuss the EoL scenario of the LCD-TV and illustrate how parts of the TV have been classified according to the different treatments.

7.2.1 Reusable parts

No reusable parts have been currently detected in the LCD-TVs. However, it is not excluded that some reusable parts could be introduced in future designed product. For this reason, reusable parts (if any) have been introduced in the scenario.

7.2.2 Parts for selective treatments

According to the WEEE Directive[131], the following components have to be removed from the LCD-TV:

- Backlighting lamps (containing mercury)
- liquid crystal displays – LCD - (together with their casing where appropriate) of a surface greater than 100 cm^2
- Printed circuit boards greater than 10 cm^2
- Capacitors
- External electric cables
- plastic containing brominated flame retardants[132, 133]

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[130] Data based on direct measurements into different recycling plants.

[131] Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)

[132] Brominated flame retardants (BFR) should be divided into two categories: polybrominated biphenyls (PBB) Polybrominated diphenyl ethers (PBDE) that have been phased out by legislation and are almost not contained anymore in WEEE [Tange et Slijkhuis, 2009], and other BFR that are not restricted and currently in use. Only this last category of BFR has been considered in the current analysis.

[133] It is currently observed an intensive research to develop processes for the recycling of plastics with flame retardants. There are some evidences in the scientific literature of technologies for the sorting of plastics with flame retardants, as for example by X-ray fluorescent (XRF) spectroscopy combined with other systems (including Near Infrared Spectroscopy and other techniques), thanks to which different types of flame-retardants (FRs) can be identified and pure resin with FRs can be separated [Di Maio et al., 2010]. However the representativeness of their use in the EU is not available. Data from IEC/TR 62635 have been assumed as the most representative currently available.

Backlighting lamps contains small amounts of mercury and for that reason they have to be carefully extracted and further treated in special plants. It has been observed in some plants the recycling of glass from lamps. Some experimental plants have been recently tested for the recovery of other valuable materials including some rare earths [Rabah, 2008]. However, no data are available about recycling rates of glass or other relevant materials. It is therefore assumed a recycling rate of 0% (in accordance with values proposed by the IEC/TR 62635).

Also LCDs have to be carefully separated by other components. LCDs can contain several different materials including heavy metals and CRMs (indium). It is estimated that 74% of all the indium consumed in the EU-27 is embedded in flat display panels [EC, 2010].

"Indium is difficult to recycle and the process is energy intensive and time consuming. Only very low levels of Indium are recycled from old scrap as there is lack of suitable facilities. Furthermore, it is not currently economically viable for most indium sources such as indium tin oxide (ITO) in flat panel displays and photovoltaic panels" [Oakdene Hollins, 2011].

According to current EoL practices, LCD screens are landfilled. However in some cases LCDs are temporarily stored[134], also in line with the growing interest for their recycling. Temporary stocks of untreated LCD screens could be recycled in the next future, thanks also to potential technology developments [ENPA, 2011].

The LCD TV contains also a variable number of very different PCBs, the majority of them larger than 10 cm^2. Different PCBs are generally sorted by recyclers according to their content of valuable materials (e.g. gold, silver, platinum and palladium). It is worth of note that PCB smaller than 10 cm^2 (generally in foil) are also those richer of precious metals.

Capacitors are contained into PCB. According to the WEEE Directive, capacitors containing polychlorobiphenyl should be selectively treated. However, according to recyclers, capacitors containing polychlorobiphenyl are generally not installed in LCD-TV. Capacitors with a diameter larger than 2.5 cm are separated from PCBs during the product dismantling.

External cables are easily extracted before the product dismantling. Their processing does not cause particular problems. Analogously plastic containing not restricted brominated flame retardants (if any) are generally shredded and afterwards separated mechanically by density systems.

7.2.3 Parts for selective recycling

Parts for selective recycling are those embodying one or more recyclable materials which are worth to be manually dismantled and separately recycled. This is performed if there is an economic convenience on doing it.

In the LCD TV these parts include:

- Internal cables
- Some large homogeneous plastic components

[134] According to private communications from some recyclers.

- Ferrous metal.

Internal cables are separated during the dismantling of other components and addressed to recycling (as for external cables). Their dismantling does not cause particular problems.

Concerning plastics, some relevant components for recycling have been identified in LCD TV, including:

- o back / front covers, support and various frames (mainly in ABS and HI-PS)
- o light guide plate (polymethyl methacrylate - PMMA)
- o plastic foils (various)

Back / front covers are generally dismantled to access to inner parts. However these are not always sorted from other plastics, mostly because their identification is not always immediate (e.g. due to the presence of plastic marking). It is assumed that ABS / HI-PS large plastic frames (larger than 200 g) are sorted from other plastics for selective recycling if easy to be identified (time for identification <10 sec) and if the recyclers established a commercial recycling route for such materials.

Concerning PMMA light guide and plastic foils, these are generally easy to be identified and sorted. The high level of purity of these plastics justifies their separation also due to their relevant economic value. Furthermore, their mass is generally relevant: PMMA board can have a mass ranging from one to several kilograms (depending on the dimension of the TV); the mass of plastics foils is ranging to some hundreds of grams. Concerning the recycling rates of PMMA boards, no data are available in IEC 62635 or in the literature. However, according to recyclers, there are evidences of established systems for their recycling and distillation for the production of new boards (virgin). A 94% recycling rate and 95% recovery rate are estimated, in line also with similar figures in IEC 62635 for other plastic parts made for selective recycling.

Few data are available concerning the recycling of plastics foils. Some examples of selective recycling have been observed, but these practises are not systematically applied by recyclers. Data concerning recycling/recovery rates of such plastics are missing.

Finally, it has been observed that ferrous metal parts, when identified, are separated from other metal and address to selective recycling. This allows a higher level of purity of the metal fraction, avoiding potential contamination with some elements (e.g. copper) that decrease the value of recyclability of steel close to zero [Brezet and van Hemel, 1997]. Therefore, magnetic ferrous parts are identified by magnets and addressed to selective recycling, while non-magnetic steels are shredded with other metals and sorted by mechanical systems.

7.2.4 Parts difficult to process

Being the EoL treatment of LCD-TV based on manual dismantling, part difficult to process are mainly those that can represent a risk for workers due to their content of hazardous substances (as for example backlighting lamps and LCD). These parts require special attentions to not be broken and release heavy metals. However, these parts belong also to the parts for selective treatments and these will be not discussed in this section.

7.2.5 Other parts (for material separation)

Remaining parts includes:

- various metal frames and covers (made by different materials)
- small plastic parts (from various frames and covers);
- speakers (constituted by metals and some plastics)
- Fans (when included).

These parts are generally disassembled during the dismantling of other TV's components. Some multi-material parts (as fan and speakers) are afterwards processed by shredders for further separation of materials.

7.3 Bill of material of LCD-TV case-study

The selected case study is a LCD-TV (20.1'' screen dimension) with an integral Cold Cathode Fluorescent Lamp (CCFL) backlight system. Table 58 illustrates the BOM of the case-study. Data have been directly measured in a recycling plant[135, 136].The overall mass of the TV is 7.19 kg. The full manual disassembly of the TV required about 7 minutes, being the backlighting system one of the last extracted parts.

[135] The composition of reflecting plastic foils in LCD is not available. According to reference, their composition is variable, including, among the others, polyester polyvinylidene chloride and PET [Lee and Cooper, 2008].

[136] Concerning unspecified composition of plastics, speakers and fan, the following assumptions have been done: unspecified plastics (PP with additives 50%; Styrene-acrylonitrile resin-SAN 50%); speakers (85% steel, 25% PET 15%); fan (PP with additives 95%; steel 5%).

Table 58 BoM of LCD-TV

Component	Materials	Mass [g]	Treatments	Disassembly
Components: Frames / covers				
Back cover	ABS	920	mechanical treatments	Full manual disassembly: about 7 minutes
Main front cover	ABS	340		
Support	ABS	250		
Secondary front covers	PC	15		
	plastic (unspecified)	98		
Main metal frame	Iron/steel	1580	Separation for recycling	
Metal frames (n°2)	Iron/steel	261		
PCB support	Iron/steel	48		
Support for cable plugging	Iron/steel	34		
	plastic (unspecified)	38	mechanical treatments	
Internal support	Aluminium	353	Separation for recycling	
Lamps support	Aluminium	30		
Components: PCBs and connectors				
Main PCB	Various (rich in precious metal)	245	Separated on the basis of richness of precious metals and addressed to further treatments for recycling	
PCB (secondary)		61		
PCB (secondary) *		1		
PCB	Various (very rich in precious metal)	55		
film connectors: n° 4		4		
PCB (secondary)	Various (poor in precious metal)	300		
PCB (secondary)		8		
Component: LCD screen				
LCD (larger than 100 cm^2)	Glass, plastics, others (indium: 48.2 mg)	473	Landfill	
Plastic light guide	PMMA	1565	Sorted during the disassembly for further treatments	
Plastic foils	Plastics	100		
Fluorescent lamps (n° 2)	Glass + various (Hg: 8mg; rare earths: 5.8mg)	8	To special treatments for Hg extraction	
Other components				
Capacitors (n°2, diameter larger than 2.5cm)	Various	9	Landfill	
Fan	plastic; steel	19	mechanical treatments	
External cables	Copper; plastic	120	For recycling	
Internal cables		25	For recycling	
Speakers	Steel; plastics	196	Separation for recycling	
Screws	Iron/steel	30		

* PCB smaller than 10 cm^2

7.3.1 Detail of some key components and materials embodied in LCD-TV

Some additional information concerning the composition of some parts has been derived from the scientific literature. In particular:

- The composition of LCD screen consists of approximately 87.2% glass, 12.7% plastic foil and 0.1% liquid crystals [Kim et al., 2009]. Plastic foils are assumed made by 33% polyester, 33% polyvinylidene chloride and 33% PET [Lee and Cooper, 2008].
- The content of indium in LCD is estimated 102 mg per kg of LCD screen [Gao et al., 2009], equivalent to about 0.21 g for the considered case-study product.

- The case-study TV contains two fluorescent lamps (as observed during its dismantling). However their composition was not known. According to references, mercury content is estimated to be 4 mg per lamp [IZM, 2007]. It is also assumed that lamps also contain white powder coating the inner surface of the glass tube, rich in Rare earth (including Yttrium and Europium). It is estimated a content of 5.8 mg of rare earths in the LCD-TV[137].
- Plastic parts can contain various flame retardants and also CRM (antimony trioxide generally used as a synergist to improve the performance of other flame retardants [Oakdene Hollins, 2011]). It is highlighted that currently, according to communications from recyclers and publications in the scientific literature, plastics containing flame retardants are generally landfilled and/or energy recovered[138]. No figures available about the content of flame retardants in case-study TV are available. In order to calculate the RRR indices, some assumptions about flame retardants have been introduced in section 7.4 and subsequent.

It is also noticed that speakers generally embody magnets. In some cases neodymium can be used in magnets for high-quality devices (e.g. in tweeters). However, detailed data are not available and content of neodymium is not considered.

Concerning the composition of PCB, average figures are assumed (estimated from [Mohite, 2005] analogously to the WM case-study). The content of precious metals in PCBs is instead illustrated in the following Table 59.

Table 59 Content of platinum/palladium and other precious metals in different typologies of PCB into LCD-TV (data estimated from [ADEME, 2008; UNEP, 2011b]).

	Category of Printed Circuit Board		
	Poor (g/ton)	Intermediate / Rich (g/ton)	Very Rich (g/ton)
Palladium	19	99	110
Platinum	-	-	40
Silver	250	1300	1000
Gold	60	490	600

According to Luda, (2011) the recycling of metals PCB can currently occur by different processes. Percentages of recovery of palladium, platinum and other precious metals are variable and depend on the treatment that the WEEE will undergo. Concerning the recycling percentages of various metals in the PCB values of Table 37 are assumed.

[137] Average content of white powder in fluorescent lamps: 2.2% in weight; content of Yttrium: 1.65% in mass of powder; content of Europium: 1.62% in mass of powder [Rabah, 2008].

[138] Some plants for the recycling of plastics with flame retardants have been developed. However figures about their representativeness in the EU context and their performance are not available.

7.4 Analysis of the case-study: LCD TV

The following paragraphs illustrate the analysis of EoL treatments of the case-study TV. The EoL scenario of the TV is illustrated in Table 60.

In particular, the manual disassembly is mainly addressed to the extraction of fluorescent lamps, LCD screen (as regulated by the WEEE Directive). During the disassembly the following parts are also separated and sorted for selective treatments and recycling:

- ferrous metals
- non ferrous metals (mainly aluminium)
- electrical cables
- PCBs (further subdivided on the basis of their content of valuable materials[139])
- PMMA board and plastic foils
- Other plastics.

[139] The sorting of PCB based on their content in precious metal has been based on the expert judgment of the recyclers.

Table 60 EoL scenario of case-study LCD-TV 20.1''

Part	Mass [kg]	Conditions	Pre-processing	Further treatment
No parts to be reused	-	-	-	-
Fluorescent lamps	0.008	Carefully manually separated	manual dismantling	Partial recycling
LCD screen	0.473	It has to be extracted (surface > 100 cm^2)	manual dismantling	Landfill
PCB (n° 1 - very rich)	0.055	Has to be extracted (larger than 10 cm^2)	manual dismantling	Recycling
PCBs (1 main board + 1 secondary board: rich)	0.306	Have to be extracted (both larger than 10 cm^2)	manual dismantling	Recycling
PCB (n° 2 secondary boards: poor)	0.308	Have to be extracted (both larger than 10 cm^2)	manual dismantling	Recycling
connectors; n° 4 films - very rich	0.004	Selective treatment not necessary, but manually separated for specific recycling due to their large content of precious metals	manual dismantling	Recycling
PCB (n° 1 secondary: rich)	0.001	Selective treatment not necessary, but manually separated for specific recycling (rich)	manual dismantling	Recycling
Capacitors (n° 2)	0.009	Have to be extracted (diameter larger than 2.5 cm)	manual dismantling	Landfill
No data available about brominated flame retardants	-	-	-	-
External electrical cables	0.12	Has to be extracted (no specific problems detected)	manual dismantling and sorting	Recycling
Internal Electrical cables	0.025	Separated during dismantling of other components (no specific problems observed)	manual dismantling	Recycling
Large plastic parts (ABS): front / back covers / support	1.51	although larger than 200g, not identified (marking not present or visible)	manual dismantling + unsorted shredding with other plastics	Recycling
PMMA board	1.565	Larger than 200 g.	manual dismantling (and sorted separately from other plastics)	Recycling
Plastic foils (unspecified)	0.1	Commercial recycling route not established	manual dismantling + unsorted shredding	Energy recovery
Other plastic parts	0.151	-	manual dismantling + unsorted shredding	Partial recycling / Energy recovery
Metal parts (ferrous) including screws	1.871	larger than 50g and identified (by magnets)	manual dismantling	Recycling
Other ferrous parts	0.082	-	manual dismantling and shredded with other metals	Recycling
Non-ferrous metal parts (assumed aluminium)	0.383	-	manual dismantling + mechanical separation	Recycling
Speakers (steel content assumed 75%)	0.196	-	manual dismantling and shredded with ferrous parts	Recycling
Fans (unspecified plastics)	0.019	-	manual dismantling + shredded with plastics	Partial recycling / Energy recovery

7.4.1 Calculation of the RRR indices for the case-study LCD-TV

The following section describes the calculation of the RRR indices for the LCD-TV.

7.4.1.1 Reusability rate

No reusable parts are detected. Reusability rate of the TV is: $R_{Use} = 0\ \%$.

7.4.1.2 Recyclability rate

The Recyclability rate is calculated in the following data-sheet. It results that the Recyclability rate of the TV is: R^*_{cyc} = 71.1%. This value is high and in line with recycling targets established by the recast of WEEE directive [European Council, 2012]. However, it is highlighted that the index here discussed focuses on the 'recyclability' as potential at the design stage, while the WEEE Directive refers to target values of recycled WEEE among some macro-categories[140].

Table 61 Calculation of the Recyclability rate of case-study LCD-TV 20.1''

Product Details					
Product	Mass (m) of the product [kg]				
LCD - TV	7.19				
Parts for selective treatment:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Fluorescent lamps	various	0.008	0%	0.0E+00	no data available
LCD screen	various	0.473	0%	0.0E+00	IEC 62635
PCB (rich and very rich)	various	0.361	18.7%	6.8E-02	IEC 62635
PCB (poor)	various	0.308	18.7%	5.8E-02	IEC 62635
Capacitors	various	0.009	0%	0.0E+00	IEC 62635
External cables	Copper and plastics	0.12	24%	2.9E-02	IEC 62635 (cable - low current)
Parts for selective recycling:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
connectors films	various	0.004	18.7%	7.5E-04	estimated from IEC 62635, as for PCBs rich
PMMA board	PMMA	1.57	94%	1.5E+00	estimation based on
Internal cables	copper + plastic	0.03	24%	6.0E-03	IEC 62635 (cable - low current)
Large ferrous parts	steel/iron	1.87	95%	1.8E+00	IEC 62635
Parts difficult to process:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
no parts					
Other parts (for material separation):					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Non ferrous metal parts	aluminium	0.38	95%	3.6E-01	IEC 62635
Steel components (various)	Steel	0.08	94%	7.7E-02	IEC 62635
Small printed circuit board (poor)	various	0.001	14%	1.4E-04	IEC 62635
ABS components (Various)	ABS	1.51	74%	1.1E+00	IEC 62635
Other plastic parts	PP (with other additives)	0.08	0%	0.0E+00	IEC 62635
	SAN	0.08	0%	0.0E+00	IEC 62635
	Plastic foils (various)	0.10	0%	0.0E+00	IEC 62635
Speakers	steel	0.147	94%	1.4E-01	IEC 62635
	plastic (PET)	0.049	0%	0.0E+00	IEC 62635 (other plastics)
Fan	plastic (PP with other additives)	0.02	0%	0.0E+00	IEC 62635
	Steel	0.001	94%	8.9E-04	IEC 62635
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				**5.11**	
Recyclability rate (*R^*cyc*) [%]	**71.1%**				

[140] It is also highlighted that the targets of the WEEE Directive based on the measured amount of wastes treated in the recycling plants, while the calculation of the recyclability rates are based on the assumed values of recycling/recovery rates of different materials/components as in the IEC/TR 62635 (including also the efficiency of the separation of the materials and their effective losses).

7.4.1.3 Recyclability rate (for plastics)

The previous Recyclability rate index has been calculated for all the materials embedded in the product. However, as discussed in the guidance documents, the calculation of the Recyclability rate could be restricted to some specific materials[141]. The advantage of the introduction of such index is to focus on the flows of some materials whose recyclability is intended to be analyzed / improved.

In particular, the case-study LCD-TV is largely constituted by plastics (over 50% in mass in the studied product), which largely influence the recyclability per weight of the product. For this reason, the recyclability rate restricted to the plastics in the product has been calculated (Table 62). It is observed that value of the rate is quite high (77.8%), mostly related to the recyclability of the PMMA board and the ABS frames.

However the calculation was influenced by two main assumptions:

- ABS parts have no flame retardants nor filler (no evidences from the product and technical specifications)
- PMMA board is selectively addressed to special plants for its recycling and recycling rate of 94%[142].

[141] Report n° 3 – Chapter 1.3.2.2.

[142] The IEC/TR 62635 does not provide a value of recycling rate for PMMA selectively separated for recycling. According to IEC/TR a value of 0% should be considered (as the IEC/TR 62635 generically assumes for all other polymers no tabulated). However, the survey of recyclers showed that the commercial recycling routes for PMMA board are generally established. It has been assumed a value of 94% recycling rate for PMMA analogous to the recycling rates of other homogeneous plastic components (e.g. ABS, PP and HIPS) as in the IEC/TR 62635.

Table 62 Calculation of the Recyclability rate for plastics of the LCD-TV 20.1''

Plastics in the Product					
Product	**Mass (m) of the plastics [kg]**				
LCD - TV	3.3				
Parts for selective treatment:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
no parts					
Parts for selective recycling:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
PMMA board	PMMA	1.57	94%	1.5E+00	estimation based on communication from recyclers
Parts difficult to process:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
no parts					
Other parts (for material separation):					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
ABS components (Various)	ABS	1.51	74%	1.1E+00	IEC 62635
Other plastic parts	PP (with other additives)	0.08	0%	0.0E+00	IEC 62635
	SAN	0.08	0%	0.0E+00	IEC 62635
	Plastic foils (various)	0.10	0%	0.0E+00	IEC 62635
Fan	plastic (PP with other additives)	0.02	0%	0.0E+00	IEC 62635
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				**2.59**	
Recyclability rate of Plastics (*R^* cyc*) [%]		**77.8%**			

However, if ABS would contain flame retardants[143] and/or fillers, its recyclability would be 0% (as suggested by the IEC/TR 62635). For example, assuming that frames contain flame retardants, the plastic Recyclability rate of the LCD-TV would become 44%.

Evidences of use of flame retardants and fillers in the case-study are missing. A detailed marking of plastics parts (e.g. in accordance to ISO1043-2 and ISO 1043-4 [ISO 1043-4, 1998; ISO 1043-2, 2011]) could underpin the manual sorting of the plastics during the EoL treatments of the product. Additional research on the use of flame retardant and recyclability of plastics is also needed, including also safety considerations[144].

Therefore, a high value of the Recyclability rate of plastics in the LCD-TV can be reached only if:

- Recyclable plastics (e.g. ABS, HI-PS, PP) are used to manufacture the main plastic frames and support

- Large recyclable plastic frames do not contain flame retardants and/or fillers

143 According to the amended standard EN 60065, new television sets should be designed in such a way that the chance of ignition and the spread of fire due to an accidental candle flame is minimized. This will imply the use of flame retardants in new devices.

144 It is highlighted that flame retardants are also used in order to accomplish to safety requirement on the flammability of the products.

7.4.1.4 Recoverability rate

The Recoverability rate is calculated in the following data-sheet. It results that the Recyclability rate of the TV is: R_{cov} = 75.3%.

Table 63 Calculation of the Recoverability rate of case-study LCD-TV 20.1''

Product Details					
Product	**Mass (m) of the product [kg]**				
LCD - TV	7.19				
Reusable Parts:					
Part		**Mass ($m_{reuse,i}$) [kg]**	**Evidences for the reuse of the part**		
No reusable parts detected		0			
Parts for selective treatment:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recovery rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Fluorescent lamps	various	0.008	0	0.0E+00	no data available
LCD screen	various	0.473	0%	0.0E+00	IEC 62635
PCB (rich and very rich)	various	0.361	61%	2.2E-01	IEC 62635
PCB (poor)	various	0.308	57%	1.8E-01	IEC 62635
Capacitors	various	0.009	0%	0.0E+00	IEC 62635
External cables	Copper and plastics	0.12	24%	2.9E-02	IEC 62635 (cable - low current)
Parts for selective recycling:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recovery rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Connectors films	various	0.004	61%	2.4E-03	estimated from IEC 62635, as for PCBs rich
PMMA board	PMMA	1.57	95%	1.5E+00	estimation from recylers communications
Internal cables	copper + plastic	0.03	24%	6.0E-03	IEC 62635 (cable - low current)
Large ferrous parts	steel/iron	1.87	95%	1.8E+00	IEC 62635
Parts difficult to process:					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recovery rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
no parts detected					
Other parts (for material separation):					
Part	**Materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recovery rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Non ferrous metal part	aluminium	0.38	95%	3.6E-01	IEC 62635
Steel components (various)	Steel	0.08	94%	7.7E-02	IEC 62635
Small printed circuit board (poor)	Various	0.001	57%	5.7E-04	IEC 62635
ABS components (Various)	ABS	1.51	75%	1.1E+00	IEC 62635
Other plastics	PP (with other additives)	0.08	5%	3.8E-03	IEC 62635
	SAN	0.08	5%	3.8E-03	IEC 62636
	plastic foils (various)	0.10	5%	5.0E-03	IEC 62636
Speakers	steel	0.147	94%	1.4E-01	IEC 62635
	plastic (PET)	0.049	5%	2.5E-03	IEC 62635
Fan	plastic (PP with other additives)	0.02	5%	9.0E-04	IEC 62635
	Steel	0.001	94%	8.9E-04	IEC 62636
Sum of recoverable parts (Σ $m_{recyc,i}$ * RCR_i) [kg]				**5.43**	
Recoverability rate (*R cov*) [%]		**75.5%**			

7.4.2 Calculation of the RRR Benefit rates for the case-study LCD-TV

The following sections apply the methods for the calculation of the RRR Benefits rates as introduced and discussed in Report n° 3 – Chapter 2.

7.4.2.1 Life cycle impacts of the LCD-TV

Life-cycle impacts of the TV are necessary for the calculation of the RRR benefits ratios. For the calculation of the Life-cycle impacts the following assumptions have been applied:

- Assumptions about the production of materials:
  - Bill of Materials: as in Table 58.
  - Content of precious metals in film connectors assumed as that of very rich PCBs (Table 59);
  - Life-Cycle-Inventory data of materials and components from various references [ecoinvent; ELCD, 2010; PE; BUWAL; PlasticsEurope];
  - Impacts of packaging not considered.
- Assumption about the manufacturing phase:
  - Energy consumption for the manufacturing of the PCB estimated from [Williams, 2004];
  - Data concerning the energy consumption for the manufacturing and assembly of other product's components have been not available and have been neglected[145];
  - Transport of raw materials to production plant is not consider (estimated not relevant);
- Assumptions about the use phase:
  - Product life: 10 years; user behaviour assessment: 4 hours/day on-mode, 20 hours/day standby (off-mode).[IZM, 2007];
  - Average energy consumption in different modes: on-mode (65 W per h), standby (1 W per h)[146];
  - Overall yearly energy consumption (0.102 MWh): overall energy consumption during product time (1.02 MWh);
  - Distribution of the product to consumers (estimation): (inventory data of emission for transport from [ELCD, 2010]);
- Assumptions about the impacts of EoL;

[145] The impacts of manufacturing of components are generally not relevant for several impact categories. For example, according to preparatory study for Ecodesign implementing measures manufacturing accounts for about 1% - 2% of the considered impacts [IZM, 2007]). In the present study, manufacturing has been considered negligible.

[146] These data have been derived from the technical specifications of the product. However, it is highlighted that these data refer to a product that reached its EoL and, therefore, energy consumption during the use phase could be overestimated and not in line with the consumption of modern devices. Actually, the assumption of lower consumption during the use phase would indeed change the results and would bring much higher significance of impacts during the other life cycle stages.

- Inventory data about the landfill of metals, plastics and inert from [ELCD, 2010].
- Life-Cycle-Inventory data of recycled materials from various references [BUWAL, 1996; ecoinvent; PE];
- Impacts due to the sorting of materials have been neglected[147].

7.4.2.2 Reusability benefit rate

No reusable parts are detected in the case-study. The Reusability benefit rate is therefore 0%.

7.4.2.3 Recyclability benefit rate

Recycling rates of materials are those used for the Recyclability rate index, with the following additional assumptions:

- Recycling rates of copper, gold, silver, platinum and palladium are those introduced concerning the WM case-study (section 5.3.1.2). Recycling rate of Platinum is assumed equal to that of Palladium
- Recycling rates of plastics of PCB are assumed null (thermoset plastics not recyclable).

It is important to underline that life-cycle inventory data of recycled plastics are missing in all the main life-cycle inventory databases. Although the contribution of plastics for some impact categories (e.g. the ADP-elemental impact) is generally negligible (according to various references) contribution of recycled plastics to impact categories could relevant (e.g. ADP fossil). Furthermore, plastics represent a relevant percentage of LCD-TV's (around 50%). Therefore it is assumed to roughly estimate impacts of recycled plastics as 24% of primary ones[148].

Table 64 illustrates the calculation of the recyclability benefit ratio for the indicator "Abiotic depletion elemental". It results that the Recyclability Benefit ratio for ADP amounts to: 95.1%. It means that, following the assumption for the EoL of the product, a saving of almost all the life-cycle ADP impact can be achieved. These are percentages are mostly related to the large recovery of precious metals in PCBs. Table 65 and Figure 16 illustrate the recyclability benefit ratio calculated for other impact categories.

It is interesting to couple the life cycle impacts of the product (Figure 17) with the results of the Recyclability benefit rates. It is highlighted that:

- the use phase is dominating (from 85% to 99%) various impact categories (e.g. GWP, ozone depletion, acidification, Eutrophication and photochemical oxidant potentials);

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[147] Impacts due to the manual/mechanical sorting consist mainly of electricity consumed by tools or machines (e.g. shredders). However, it is assumed that electricity consumption is dominated by the use phase (according also to other study in the literature [IZM, 2007]) and consequently electricity consumption for sorting is neglected. Other emissions during the recycling (e.g. release of dust and chemicals) and other potential environmental impacts (e.g. noise levels, safety of workers) have been not included because no inventory data were available.

[148] This figure is estimated on the figures of recycled plastics in section 3.5.4, according to the HI-PS plastic and concerning the global energy requirement indicator (impact of recycled plastic from [Ross and Evans, 2002]).

- the production of materials is dominating (99%) the ADP-element category, and it is very relevant for human toxicity (62%), aquatic ecotoxicity (55%) and terrestric ecotoxicity (45%);

- the detail of product's components (Table 66) illustrates that the PCBs are almost fully responsible of the ADP-element impacts, and largely relevant for the human toxicity and ecotoxicity impacts. The LCD and backlight lamps[149] contribute from 1% to 3% of various categories. The PMMA board contributes to the aquatic ecotoxicity (1.7%) and furthermore, it is the product's part that contributes the most on some other impact categories, including Eutrophication (3.7%), ADP-fossil (3%) and GWP (2%).

Comparing the LCA impacts with the Recyclability benefit rates, it is estimated that there are some improvement potentials for the ADP-element impact and higher improvement potentials for the human toxicity and aquatic toxicity impacts. Some improvement potentials are also estimated for other impact categories (e.g. ADP-fossil), mainly related to the improved recycling of plastics.

Table 64 Calculation of the Recyclability benefit rate of case-study LCD-TV 20.1'' for the ADP-element impact category

Product Details	
Product	**Mass (m) of the product [kg]**
LCD-TV	7.19
Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential elemental (ADP)
Unit of measure	kg $Sb_{eq.}$

Recyclable part	Material	Mass ($m_{recyc,i}$) [kg]	Recycling rate (RCR_i) [%]	Impacts for the production of virgin material (V_i) [unit/kg]	Impacts for the Disposal (D_i) [unit/kg]	Impacts due to recycling (R_i) [unit/kg]	$m_{recyc,i}$*RCR_i *(V_i+D_i-R_i)	References and details
Cables (internal and external)	copper	0.145	24%	2.03E-03	1.14E-09	2.19E-04	6.30E-05	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
PCB	gold	2.043E-04	97%	5.82E+01	1.14E-09	2.22E-04	1.15E-02	primary / secondary gold (ecoinvent); (recycling rate from Meskers et al., 2009)
	silver	5.351E-04	92%	1.37E+00	1.14E-09	3.80E-06	6.72E-04	primary / secondary silver (ecoinvent); disposal of metals from (ELCD)
	palladium	4.274E-05	99%	6.60E-01	1.14E-09	1.47E-03	2.79E-05	primary / secondary palladium (ecoinvent); disposal of metals from (ELCD)
	platinum	2.360E-06	99%	2.50E+00	1.14E-09	1.47E-03	5.85E-06	primary / secondary platinum (ecoinvent); disposal of metals from (ELCD)
	copper	1.32E-01	95%	2.03E-03	1.14E-09	2.19E-04	2.27E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Frames	ABS	1.51	74%	1.50E-06	1.05E-08	3.61E-07	1.29E-06	primary ABS and plastic disposal from ELCD; no data about ABS recycling; (assumed roughly 20% of primary production)
Light guide	PMMA	1.57	94%	8.47E-06	1.05E-08	2.03E-06	9.48E-06	primary PMMA from PlasticsEurope; plastic disposal from ELCD; no data about PMMA recycling (assumed roughtly 24% of primary production)
Large ferrous parts	Steel	1.87	95%	7.15E-08	1.14E-09	0	1.29E-07	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)
Various	aluminium	0.38	91%	1.72E-05	1.14E-09	1.23E-05	1.72E-06	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	Steel	0.23	94%	7.15E-08	1.14E-09	0	1.57E-08	steel sheet (primary secondary) from (BUWAL); disposal of metals from (ELCD)

Life Cycle impacts of the product:		
A. Impacts due to the production of materials	1.3E-02	Details: (provided in the text)
B. Impacts due to the manufacturing of the	4.1E-09	Details: (provided in the text)
C. Impacts due to the use of the product (U_n) [unit]	4.1E-05	Details: (provided in the text)
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]	5.4E-07	Details: (provided in the text)
Sum of the impacts (A +B+C+D)	1.32E-02	kg $Sb_{eq.}$
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]	1.25E-02	kg $Sb_{eq.}$
Recyclability Benefit rate ($R'_{cyc,n}$) [%]	95.1%	

[149] It is highlighted that the impacts of LCD and lamps have been indirectly estimated from reference data. The resulted figures could be therefore underestimated.

Table 65 Recyclability benefit rate of case-study LCD-TV 20.1'' for different impact categories

	Impact category											
	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Aquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Sum of benefits	2.4E+01	6.8E-01	1.2E-01	1.0E-06	1.4E-01	1.9E-02	3.0E-02	7.6E+01	1.4E+00	5.9E-01	1.25E-02	3.2E+02
Life cycle impacts	6.5E+02	5.4E+00	1.6E+00	1.5E-04	1.2E+00	1.8E-01	4.7E-01	1.4E+02	3.8E+00	1.5E+00	1.32E-02	6.8E+03
	Recyclability Benefit Rate [%]											
Recyclability B. Rates	3.7%	12.5%	7.7%	0.7%	11.8%	10.5%	6.4%	55.2%	37.4%	38.9%	95.1%	4.8%

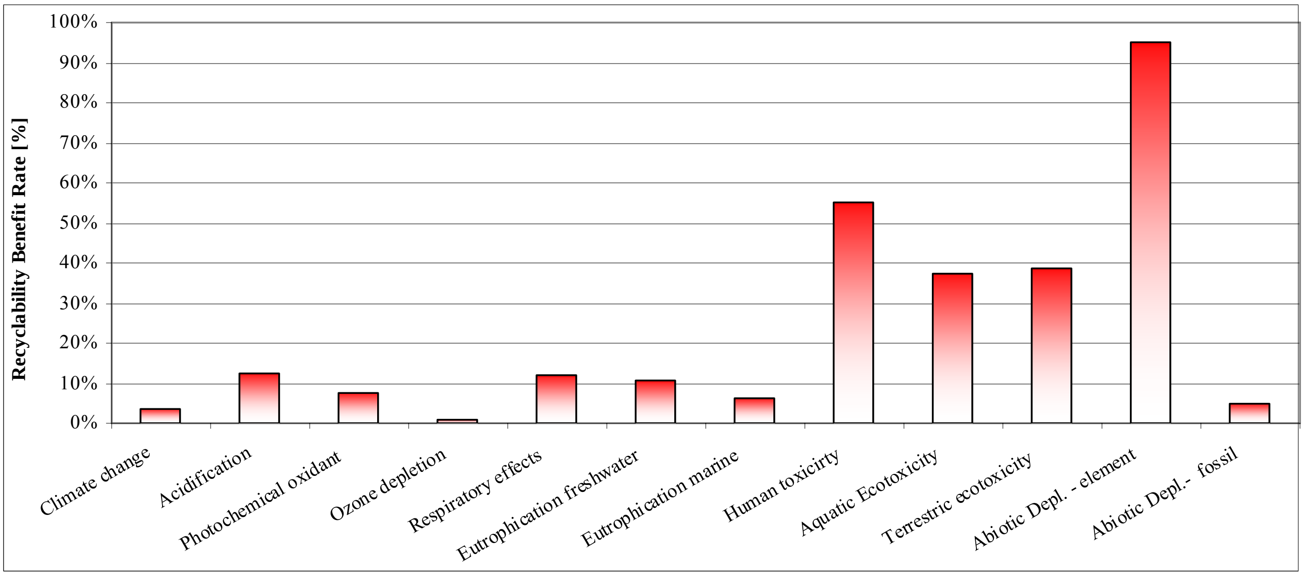


Figure 16 Recyclability Benefit rate of LCD-TV for various impact categories

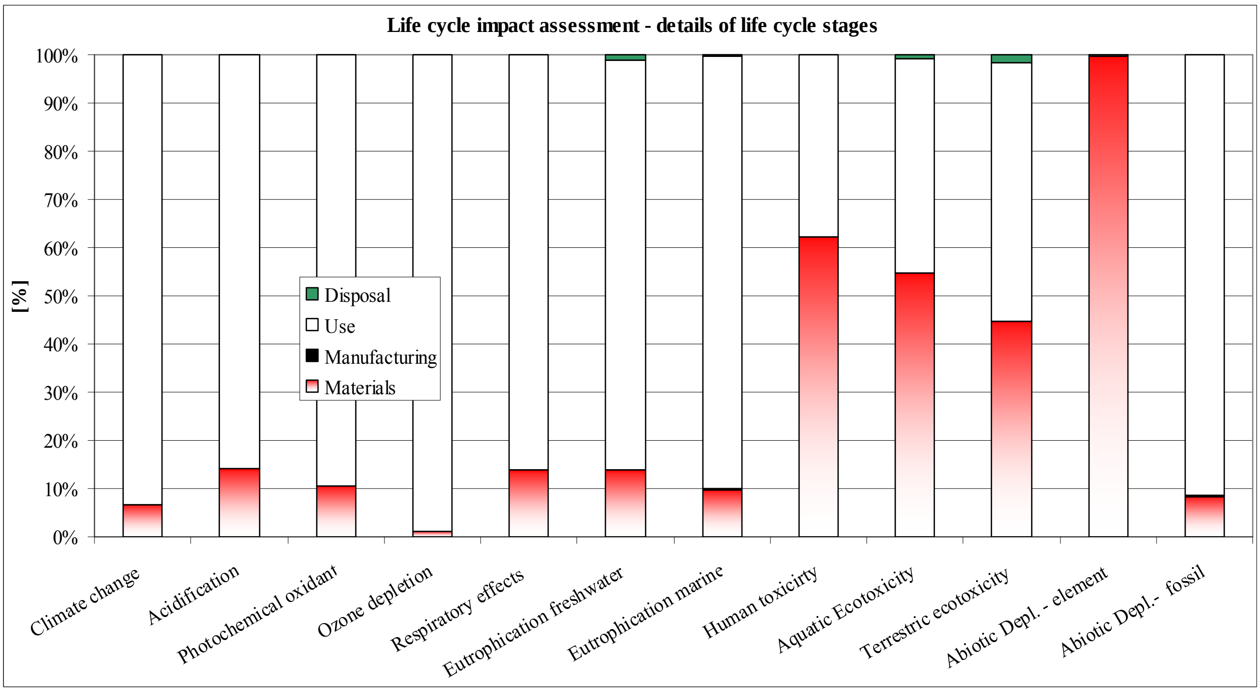


Figure 17 Life cycle impacts of the LCD-TV case-study (contribution of life cycle stages)

Table 66 Contribution of the production of some TV's parts to some life cycle impacts

Contribution of the production of some part to some life cycle impacts [%]				
	Parts			
	PCB	LCD	Lamps	PMMA board
Abiotic Depletion - element	98.5%	0.4%	-	0.1%
Abiotic Depletion - fossil	1.7%	0.5%	-	3.0%
Aquatic Ecotoxicity	35.9%	2.0%	-	2.2%
Eutrophication freshwater	5.6%	0.7%	-	3.7%
Human toxicity	46.3%	2.6%	-	0.5%
Terrestric ecotoxicity	31.1%	1.0%	2.4%	0.4%

7.4.2.4 Energy Recoverability benefit rate

Table 67 illustrates the calculation of the energy recoverability benefit ratio for the indicator "Abiotic depletion fossil".

It results that the Recoverability benefit ratio amounts to: 1.4%. It means that, following the assumption for the EoL of the product, only 1.4% of the overall energy consumption during the life-cycle of the WM2 could be potentially be recovered[150].

Table 67 Calculation of the Energy Recoverability benefit rate of the case-study LCD-TV 20.1''

Product Details	
Product	Mass (m) of product [kg]
LCD-TV	7.19

Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential
Unit of measure	MJ

Recyclable part	Material	Mass ($m_{recov,i}$) [kg]	Recovery rate (RVR_i) [%]	Heating Value (HV_i) [MJ/kg]	efficiency for electricity (η_{el})	efficiency for heat (η_{heat})	Impact for electricity (El_n) [unit/MJ]	Impact for heat ($Heat_n$) [unit/MJ]	Impact for incineration ($I_{n,i}$) [unit/kg]	($m_{recov,i}$*RVR_i*HV_i)*(η_{el}*El_n+η_{heat}*$Heat_n$) - $m_{recov,i}$*$I_{n,i}$)	References and details
PCB	Epoxy resin	0.13	90%	31	0.3	0.6	1.7	1.09	0.54	4.23	
Other plastics	SAN	0.07	5%	n.a.	0.3	0.6	1.7	1.09	0.54		High Heating Values of plastics estimated from various references; impact of electricity (EU-27 power mix) and Heat (EU-27 heat) from ELCD; impact of incineration of plastics estiamted from ecoinvent
	PP	0.07	5%	46	0.3	0.6	1.7	1.09	0.54	0.14	
Frames	ABS	1.51	75%	36	0.3	0.6	1.7	1.09	0.54	46.31	
Light guide	PMMA	1.57	95%	26	0.3	0.6	1.7	1.09	0.54	44.52	
Plastic foils	PET	0.033	5%	46	0.3	0.6	1.7	1.09	0.54	0.07	
	polyester	0.033	5%	28	0.3	0.6	1.7	1.09	0.54	0.04	
	polyvinylidene chloride	0.033	5%	n.a.	0.3	0.6	1.7	1.09	0.54		
Fan	PP	0.018	5%	46	0.3	0.6	1.7	1.09	0.54	0.04	
Speakers	PET	0.010	5%	46	0.3	0.6	1.7	1.09	0.54	0.02	

Life Cycle impacts of the product:		
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]	2.7	Details: (provided in the text)
B. Impacts due to the manufacturing of the product (M_n) [unit]	572.2	Details: (provided in the text)
C. Impacts due to the use of the product (U_n) [unit]	6173.7	Details: (provided in the text)
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]	6.0	Details: (provided in the text)
Sum of the impacts (A +B+C+D)	6754.6	MJ
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]	95.4	MJ
Recyclability Benefit rate ($R'_{cyc,n}$) [%]	1.4%	

[150] For the calculation it is assumed that plastics in electrical cables are not energy recovered [IEC 62635, 2012]. Recovery rate of epoxy resins in PCBs estimated 90% from IEC 62635 (Korean scenario).

7.4.3 Calculation of the recycled content indices

As discussed in the previous chapter, the analysis of the recycled content indices has been not performed for the LCD-TV case-study.

7.4.4 Assessment of the use of hazardous substances in the LCD-TV

The scope of the assessment is the identification of components in the LCD-TV that are potentially relevant for their content of potential hazardous substances according to the method illustrated in Report n° 3[151]. The assessment is based on the following steps:

- 'Step 1 – substances considered'. The analysis has been restricted to substances regulated by the RoHS directive.
- 'Step 2 - identification of components embodying the substances. It is highlighted that a detailed BOM of the LCD-TV was not available. The identification has been therefore performed on the basis of information collected at the recycling plants and data from the scientific literature. The following components can be potentially relevant for the analysis:
    - Fluorescent lamps, for the content of mercury (up to 4 mg per lamp)
    - LCD, due to their potential content of heavy metals[152].
    - PCB and capacitors, for the potential content of mercury and cadmium (see Table 35 for some average content) and polychlorobiphenyl.
- 'Step 3 - identification of EoL treatments of potentially relevant components'. According to the EoL scenario set (Table 60), the treatments are:
    - Fluorescent lamps: manually disassembled. The disassembly implies risks for the workers and the environment due to potential contamination by mercury. The sorted lamps are afterwards addressed to treatments for the separation of mercury;
    - PCB: manually disassembled. After sorting, PCBs are addressed to specific plants for the recovery of valuable metals, and afterwards incinerated or landfilled. No evidences about further treatments for the separation of hazardous substances potentially embedded.
    - LCD: manually disassembled. After sorting, LCDs are temporary stored and then landfilled. According to interviewed recyclers, LCD screens were previously handled as hazardous waste; nowadays the screens are considered normal waste because their content in heavy metals has largely decreased. Being LCD normal waste, they require simplified procedures for the storing. Recovery of metals and other relevant substances from LCD screen is currently under research and development in testing plants.

[151] Report n° 3 - Section 4.3.1.

[152] According to WEEE Directive, LCDs - (together with their casing where appropriate) of a surface greater than 100 cm^2 have to be removed from any separately collected WEEE

- ‘Step 4 - identification of key components’. According to the previous steps it is assessed that fluorescent lamps are a key components of the LCD-TV due to their large amount of mercury and the risk related to the current EoL treatments. PCBs and LCD screen could be other potentially relevant components but more detailed BOM are necessary for the assessment.

It is highlighted that potential requirements on the disassemblability of the lamps could contribute to the reduction of the risk of breakage of lamps during the treatments. Such requirements could be also synergic to other purposes including the improvement of the recovery of relevant substances (e.g. rare earths contained in the lamp) and durability (substitutability of the component for the prolongation of the product lifetime).

7.4.5 Calculation of the durability indices

The application of the durability indices for the TV case-study has been not performed.

7.5 Dynamic analysis of EoL scenarios for the treatment of LCD-TV

The previous sections illustrated and applied the current EU representative EoL scenario for LCD-TV, to the methods developed in Report n° 3. This scenario allows already high recycling rates for some materials and it is economically viable (although currently with high costs for manpower). However, some expected future technological and market changes are estimated to affect the recycled flows: some “automated” scenarios (based on shredding without pre-treatments and mechanical sorting) are under development and applied at testing/small scale plants. These treatments might be more economically efficient than the current EoL scenario while usually generating higher losses of recyclable materials with consequent reduced environmental benefits. Furthermore, this new plants are also intended to reduce the risks for workers due to exposition to mercury[153].

A recent study however observed that “an automated shredding process would require a suitable mercury abatement system to prevent mercury becoming airborne in the wider environment. The mercury locked in fluorescent lamps would not be readily detectable by random sampling of shredded material. Without suitable processes to isolate mercury after shredding, the shredded material would be classed as hazardous” [McDonnell et Williams, 2010].

There is plenty of evidence of technological progresses moving towards mechanical systems for the EoL treatments of LCD-TV, including open air shredders or ‘encapsulated units’ (i.e. sealed shredders operating in a controlled environment) [EMPA, 2011]. Tests showed that open-air shredders are affected by large mercury losses in the environment and therefore not in line with EU legislation.

[153] Some innovative automated plants for the treatments of the LCD-TVs in a closed controlled environment have been developed by European recyclers (see for example [Stena, 2010]). However, quantitative disaggregated data on recycling efficiency of such plants are still not public available.

On the other side new 'encapsulated unit' are still under testing / development. Although this typology of plants is still not common in the EU[154], it is estimated that it will be improved and installed in the EU in the next future, mostly because of its higher economic efficiency and reduced risks for workers. Due to the dynamic nature of the EoL scenario[155], it is possible to foresee a possible future scenario for the treatment of LCD-TVs based on mechanical treatments (Figure 18). Flows and recyclable materials are roughly estimated on the basis of available information from the literature and communication from recyclers.

Unfortunately, no detailed data are available about recycling rates and recyclability of different materials after the treatments (including the losses of mercury and their potential effect on recyclability of materials).

Figure 18 Scheme of a possible EoL treatments for the LCD TV based on mechanical treatments

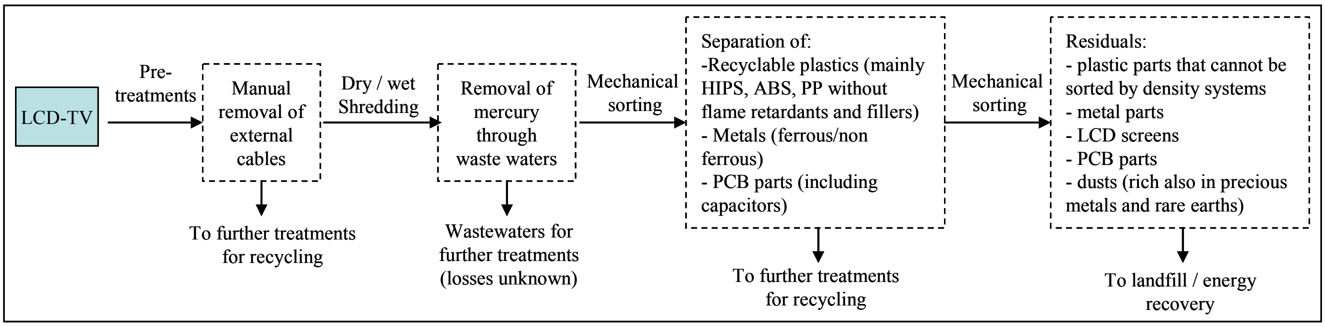


Table 68 Recycling rates of material in the potential EoL scenario of LCD-TV based on mechanical treatments

Parts	Mass [g]	Materials	Treatment	Recycling rates
Fluorescent lamps	8	Glass, dusts (including mercury and rare earths)	Mercury partially recovered in wastewaters and further treated; other parts are lost in the residues	Lamps: 0%
LCD screen	473	Various (including glass, plastics, metals and indium)	Shredded LCD parts are not recycled (due to difficulty on sorting and contamination)	LCD parts: 0%
PCBs (including capacitors)	683	various	PCB parts are sorted and partially recovered. Capacitors larger than 2.5cm (embedded in PCBs) need to be manually separated.	Copper: 60%; Silver: 11.5%; Gold: 25.6%; Platinum: 25.6%; Palladium: 25.6%. Others: 0%
External cables	120	Copper; PVC.	Manually extracted	Cables: 24% (copper)
Internal cables	25	Copper; PVC.	Shredded and difficult to sort from other plastics and metals	Cables: 0%
Plastics frames	1510	ABS	Shredded and partially sorted and recycled	ABS: 74%
PMMA board	1565	PMMA	Shredded and not separated by density systems	PMMA: 0%
Other plastic parts (including foils)	251	various	Shredded and not separated by density systems	Plastics: 0%
Metal parts (ferrous)	1953	steel	Shredded and sorted by magnetic systems	Steel: 94%
Metal parts (non-ferrous)	383	Aluminum	Shredded and sorted by eddy current systems	aluminum: 91%
Speakers	196	Steel; plastics	Shredded and mechanically sorted	Steel: 94; plastics: 0%
Fan	19	PP (with fillers); steel	Shredded and mechanically sorted	PP: 0%; steel: 94%

[154] EERA (European Electronics Recyclers Association) confirmed by personal communications that this EOL scenario is only emerging at the time of the study and that currently only treats a minor share of the flow of LCD-TV. This scenario could however become in the future one of the representative scenarios in the EU.

[155] For the description of alternative and dynamic EoL scenario for the calculation of the Recyclability and Recoverability rates, see Report n° 3 – Section 1.3.2.2.

The recycling rates[156] of various fractions are shown in Table 68, assuming that:

- Recycling rates of metals in PCB have been estimated from [Chancerel et al., 2009; Meskers et al., 2009];
- Recycling rates of ferrous metals and non-ferrous metals variable from the IEC/TR 62635;
- Recycling rates of plastic parts (ABS, PMMA, PC, PP with fillers, various plastic foils) from the IEC/TR 62635;
- Recycling rates of LCD: 0%) from the IEC/TR 62635;
- Recycling rates of shredded internal cables: 0% (estimated).

Compared to the previous disassembly-based scenario, main differences of the potential future EoL scenario are:

- recycling rates of metals in PCBs are much lower
- recycling rates of metal parts (steel and aluminium) are slightly lower;
- large losses of plastic frames, in particular recyclability of ABS decreased from 94% to 74%)
- missing recovery of PMMA and internal electrical cables
- higher losses of mercury (not estimated) and additional burdens due to wastewater treatments;

It is also highlighted that some parts (as LCD, rare earth in fluorescent lamps and plastics foils) are assumed to be not recycled in both scenarios. However, the disassembly-based EoL scenario (Table 60) can allow the sorting of such materials and potentially suitable for their recycling, once economically viable technologies would be developed. The shredding-based EoL scenario (Table 68) is instead not compatible with the recycling of such parts.

From the dynamic analysis of EoL scenarios it can be concluded that the full manual disassembly is currently a scenario economically viable and extensively applied in the EU. However, this scenario could become not competitive in the near future unless certain dismantlability requirements are enforced, also due to the growing amounts of TVs coming to the EoL. It can be assumed that the disassembly scenario will be progressively partially/fully replaced by mechanical treatments.

The dynamic analysis also assumes that some potential requirements could affect the evolution on the EoL scenarios. In particular, according to some communication from recyclers, the improvement of the disassembly of the product would make the disassembly scenario more economically competitive also in the next future.

For the dynamic analysis of the scenarios it is assumed that currently the dismantling scenario dominates (around 95%) the flows of LCD-TV at the EoL, while the shredding-based is only at testing level (5%)[157]. It is assumed that, in the medium term (around 10-15 years) the shredding-based

[156] Recycling rates of parts and materials are referred to the IEC/TR 62635 (concerning the sorting of materials after shredding), except the recycling rates of metals in shredded PCBs that refer instead to [Chancerel et al., 2009; Meskers et al., 2009]

[157] These figures have been estimated on the basis of communication from recyclers.

scenario would evolve significantly up to 60%, due to its large economic convenience. In this normal evolution of the scenarios, the shredding-based scenario would decrease to 40%.

Three evolving situations are following assumed:

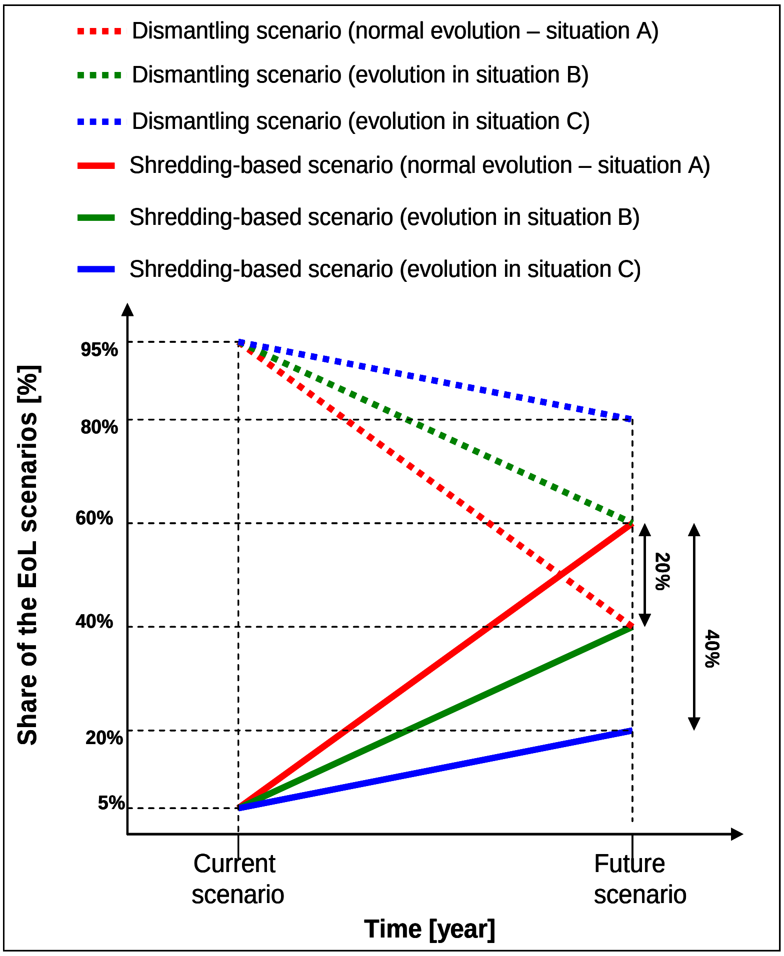
Situation A. Normal evolution of the EoL scenario (without implementing any potential ecodesign requirements on the disassemblability of the TV)

Situation B. Thanks to application of requirements on the disassemblability of some TV's parts, an additional share of 20% of the overall LCV-TVs will be in the future dismantled instead of being shredded and mechanically sorted: this is due to the fact that manual disassembly is more economically competitive thanks to requirements.

Situation C. Thanks to application of the requirements on the disassemblability of some TV's parts, an additional share of 40% of the overall LCV-TVs will be in the future dismantled instead of being shredded and mechanically sorted.

The evolution of the shares of the two EoL scenarios in the different situations has been schematically illustrated in Figure 19.

Figure 19 Evolution of EoL scenarios for the LCD-TV product group



7.6 Potential ecodesign requirements for the LCD-TV product group

The previous sections applied the methods developed in Report n° 3 to the LCD-TV case-study. The next step of the analysis consists in the selection and assessment of potential product's ecodesign requirements with relevant environmental benefits.

The identification of potential ecodesign requirements has been performed on the basis of information about the life-cycle impacts of the products (and detail of impacts of some components, as in section 7.4.2.3) and on the basis of the main outcomes of the analysis of the proposed indices (RRR, RRR benefits, content of hazardous substances). For example, the analysis of the RRR identifies the parts that are the most relevant from a weight perspective, because of their losses through the recovery chain. Similarly, the analysis of the RRR Benefits lead to a priority list of components that affects the environmental losses (see Chapter 4.), and these losses can be compared with the overall life cycle performances of the product.

This analysis identifies parts that are potentially relevant for some requirements. Afterwards, the analysis focuses on the EoL treatments of such part to identify possible risks and problems. Finally some requirements are identified in order to overcome such risks/problems and increase the benefits of the recycling of these parts.

For the particular case of the LCD-TV, the LCA analysis identified some parts that are significant for their environmental impacts and whose EoL treatments can affect largely the life cycle balance of the product. Relevant parts are:

- PCBs, embodying capacitors, are very significant for several impacts categories (Abiotic Resource Depletion-elements, Human toxicity, Aquatic Ecotoxicity and Terrestric ecotoxicity). Furthermore PCBs and capacitors can embed various CRMs (e.g. PMG, tantalum).
- Backlight lamps are relevant components for the content of hazardous substances (mercury). Lamps are also potentially relevant for the content of CRMs (various rare earths in the fluorescent dusts) and contribute more than 2% for the Terrestric ecotoxicity impact.
- LCD screen is very relevant for the content of CRM (indium). It also contributes up to 2 % for some impact categories it can embed some hazardous substances (heavy metals).
- Plastic parts (e.g. the PMMA board, plastic foils, and ABS parts) are some relevant components of the case-study LCD-TV. They represent about 50% of the overall product mass. According to analysis in section 7.4.2.3, they account for about 5% of various life-cycle impact categories (including Abiotic Depletion – fossil, Freshwater Aquatic Ecotoxicity and Eutrophication) and about 3% of GWP and Marine Eutrophication. In particular, the PMMA board represents more than 20% in mass of the TV and contributes to about 3% of the life-cycle energy consumption of the product.

Afterwards, it has been analyzed the EoL treatments of previously identified parts, in order to identify possible problems / risks that could arise. It is observed that:

- PCBs are currently manually extracted and sorted according to their typology (based on the estimated content of precious metals) and addressed to different recycling routes in order to optimize the recycling of valuable resources. However, possible future shredding-based scenarios for their separation would imply large losses. Furthermore, capacitors larger that 2.5cm are sometimes installed in PCBs and these require anyway a manual sorting.
- Backlight lamps are currently disassembled and sorted fur further treatment for the removal of mercury. However, their disassembly is generally long and it requires special cares to avoid their breakage[158]. Fluorescent dusts (rich in rare earths) in the lamps are currently separated to be stored or landfilled. Some exemplary treatment plants are under development to allow the recovery of rare earths [Rabah, 2008]. It is highlighted that the possible recovery process of rare earth is not compatible with a shredding-based scenario of LCD-TV.
- LCDs are separated to be landfilled. However, it has been observed that some recyclers are currently storing LCD screens in prevision of possible future development for the recovery of indium. It is highlighted that the possible recovery process of indium is not compatible with the shredding-based treatment of LCD-TV.
- The recycling of plastics parts is largely dependent of the EoL treatments. In particular the PMMA board can be recycled only if manually sorted by other plastics[159].
- Other plastic parts (e.g. support and internal/external frames) can be recycled but only if belonging to some typologies (ABS, HIPS, PP) and if not embedding fillers and/or flame retardants[160, 161]. From the survey of two recycling plants, it has been also observed that marking of plastics in LCD-TVs (e.g. according to ISO 11469) is only partially applied and it is generally not enough efficient (difficulties for workers to locate and identify the marking; missing identification of flame retardants and/or fillers)

On the basis of the previous analysis, the following requirements have been identified as potentially relevant for the LCD-TV product group, in order to increase and/or sustain recycling rates of different materials:

- Improvement disassemblability of key parts (PCBs, LCD screens, fluorescent lamps, PMMA board)
- Declaration of the content of CRMs;
- Improvement of the disassemblability of large plastic parts;

[158] Breakage of lamps can cause the release of mercury with risks for the workers and the environment.

[159] Current mechanical treatments based on sorting by density do not allow to separate the shredded PMMA parts from other plastics.

[160] To mechanically recycle post-user plastic waste containing brominated flame retardant, it has to be collected, sorted, separated, ground, washed and reprocessed before it can be mixed with virgin plastics of the same type for molding new products, or used on its own for alternative lower value products [BSEF, 2012]. Only in a limited number of cases are the overall plastics recycling operations economically viable because of the relatively low cost of new, virgin plastics.

[161] It is currently observed an intensive research to develop processes for the recycling of plastics with flame retardants. There are some evidences in the scientific literature of technologies for the sorting of plastics with flame retardants, as for example by X-ray fluorescent (XRF) spectroscopy combined with other systems (including Near Infrared Spectroscopy and other techniques), thanks to which different types of flame-retardants (FRs) can be identified and pure resin with FRs can be separated [Di Maio et al., 2010]. However the representativeness of their use in the EU is not available. Data from IEC/TR 62635 have been assumed as the most representative currently available.

- Threshold of the Recyclability rate for plastics.

These potential requirements are discussed in detail in the following sections.

7.6.1 Improvement of the disassemblability of key parts (PCBs, LCD screens, fluorescent lamps, PMMA board)

a. Identification of the requirements

The analysis in the previous section identified PCBs (with capacitors), fluorescent lamps, LCD screen and PMMA board as key components of the TV for various reasons. According to the current EoL scenario, these parts are manually disassembled in order to optimize the recyclable fractions and reduce the risks of releases of hazardous substances in the environment.

Based on direct measurement at two recycling plants, the full manual dismantling is highly variable and it implies from 5 minutes to 9 minutes (for LCD-TV of dimension from 20 inches to 30 inches). Furthermore, the disassembly is characterized by some difficulties, mainly:

- the disassembly of valuable recyclable parts (e.g. PCBs and some plastic parts) of TVs is often hampered by the large number and complexity of fastening systems (including e.g. up to tens of screws of different sizes), which cause long times for disassembly (e.g. due to the continuously change the tools for the disassembly).

- the time and the potential risks for the extraction of potentially hazardous parts (e.g. fluorescent lamps and LCD).

According to communications from recyclers, the time for disassembly of LCD-TV hinders the economic viability of the process. Moreover, lamps are deeply nested in the product, and their extraction is generally difficult and is affected by the risk of breaking with releases of mercury.

Currently the full manual disassembly is the scenario is economically viable thanks to the high recycling rates of some valuable materials[162]. However, it is not sure whether it is indeed fully applied to all flows of LCT-TV sets at the EoL. Moreover, this scenario could become not competitive in the near future, and could be partially/fully replaced by mechanical treatments (see section 7.5). The improvement of the disassemblability of key parts (PCBs, lamps, LCD, PMMA board) can contribute to reduce costs for manual disassembly, reduce risks for workers and the environment and increase the overall amounts of recycled masses.

Some potential requirements for the improved disassemblability of key parts are following illustrated and discussed. It is highlighted that:

[162] The current analysis focused only on LCD-TV with backlighting systems. However, other typologies of flat panel display TVs are currently under development including 'Electro luminescence TV' (with Organic Light Emitting Diodes) and Plasma Display Panels. Little information about the composition and the EoL treatments of these TVs is available, also because few devices currently reached the EoL. A more comprehensive analysis of products in the market could contribute to more precisely define future EoL scenarios for the TV product group.

- Time thresholds for the disassembly have been based on measurements at two recycling plants and on private communication from some recyclers. These thresholds are set in order to reduce the cost for labour and to optimize the recovery of recyclable and hazardous parts;

- Time thresholds for the disassembly of parts are related to the dismantling of observed devices (TVs with a dimension from 20 inches to 30 inches). Different time thresholds could be foreseen for TVs with different dimensions. A more comprehensive analysis of product in the market would be useful for such purposes.

Potential Requirement: Design for Disassembly of the PMMA board

The time for the extraction[163] of the PMMA board embedded in the LCD-TV (as performed by professionally trained personnel using tools usually available to them) shall be less than 120 seconds[164].

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on the manufacturer's website and on request of recyclers) product manual) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where the PMMA board is installed in the product, details of the components fastening systems, disassembly procedures, tools needed for the disassembly)
- The report should include the time (in seconds) needed for the disassembly and the disassembly steps undertook during the testing of the disassembly.

Potential Requirement: Design for Disassembly of the LCD screen

The time for the extraction[165] of LCD screens larger than 100 cm^2 (as performed by professionally trained personnel using tools usually available to them) shall be less than 150 seconds[166].

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on the manufacturer's website and on request of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where the LCD screen is installed in the product, details of the component's fastening systems, disassembly procedures, tools needed for the disassembly)
- The report should include the time (in seconds) needed for the disassembly and the disassembly steps undertook during the testing of the disassembly.

[163] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.
[164] Time threshold is based on estimations and measurements at two recycling plants. This value should be considered as indicative of current practises. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.
[165] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.
[166] Time threshold is based on estimations and measurements at two recycling plants.

Potential Requirement: Design for Disassembly of the fluorescent lamps

The time for the extraction[167] of all the fluorescent lamps embedded in the LCD-TV (as performed by professionally trained personnel using tools usually available to them) shall be less than 180 seconds[168].

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on the manufacturer's website and on request of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where lamps are installed in the product, details of the components fastening systems, disassembly procedures, tools needed for the disassembly)
- The report should include the time (in seconds) needed for the disassembly and the disassembly steps undertook during the testing of the disassembly.

Potential Requirement: Design for Disassembly of the Printed Circuit Board

The time for the manual disassembly of Printed Circuit Boards (PCBs) larger than $10cm^2$ and film connectors embedded in the LCD-TV (as performed by professionally trained personnel using tools usually available to them) shall be less than 180 seconds[169].

Verification:

Manufacturer shall provide free of charge technical information for disassembly (on the manufacturer's website and on request of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where the PCBs are installed in the product, details of the components fastening systems, disassembly procedures, tools needed for the disassembly)
- The report should include the time (in seconds) needed for the disassembly and the disassembly steps undertook during the testing of the disassembly.

It is also highlighted that the above requirements are interrelated. In fact, they share some common disassembly steps, and the disassembly of some parts is necessary or contributes to the disassembly of the others. For example fluorescent lamps are generally the component most difficult to be extracted, and their disassembly imply the preventively extraction of the LCD and of some of the PCBs. The disassembly of the LCD screen preventively implies the separation of the PMMA board. Therefore the above requirements could be implemented in different possibly ways:

- To implement four separate requirements (as above showed);
- To implement only some of the requirements, as for example those related to the most relevant parts (for example lamps and LCD)

[167] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.

[168] Time threshold is based on estimations and measurements at two recycling plants. This value should be considered as indicative of current practises. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

[169] Time threshold is based on estimations and measurements at two recycling plants. This value should be considered as indicative of current practises. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

- or, finally, to implement a cumulative requirement for two or more of the key parts as following showed (with a specified maximum time for disassembly).

Potential Requirement: Design for Disassembly of key parts in the LCD-TV

The time for the extraction[170] of fluorescent lamps and LCD screen larger than 100cm^2 embedded in the LCD-TV (as performed by professionally trained personnel using tools usually available to them) shall be less than 240 seconds[171].

Verification:

Manufacturer shall provide technical information for disassembly (in the manufacturer's website or on demand of recyclers) and provide (to the market surveillance authority on request) a declaration to this effect, together with appropriate supporting documentation, including:

- Disassembly report (including the schemes of where lamps and LCD screens are installed in the product, details of the components fastening systems, disassembly procedures, tools needed for the disassembly)
- The report should include the time (in seconds) needed for the disassembly and the disassembly steps undertook during the testing of the disassembly.

The selection of most suitable requirements should be based on an extensive analysis of different products in the market, involving also recyclers and manufacturers.

The measurement of the disassembly time could usefully follow a standardized procedure, which would specify the testing method including, for example, the testing environment, how to perform the disassembly, the expertise of the employed personnel, the tools to be used, etc. This procedure should also set the tolerance and sensitivity of the measurements. Some key issues for the standardisation process of the measurement are illustrated in Annex 4.

It also noticed that innovative TV sets could replace fluorescent lamps with other alternative systems mercury-free (e.g. LED systems), but no data were currently available during the present project. If no mercury was contained in future products, requirement on dismantlability of fluorescent lamps could be avoided. However the typology of requirement on dismantlability is still valid for other relevant components.

b. Calculation of the environmental benefits at the case-study product level

The next step of the analysis is represented by the assessment of potential environmental benefits related to the application of the proposed requirements to the considered case-study LCD-TV by comparing the current and the possible future EoL scenarios (according to the dynamic analysis in section 7.5), where:

- The 'disassembly scenario' reflects the current EoL treatments for the LCD-TV based on a full disassembly of the product (according to treatments in Table 57).

[170] The extraction is here intended as the manual procedure (eventually assisted by tools and machines) to separate the component granting its integrity for the next EoL treatments. The requirements should also be updated to the potential evolution of automatic or semiautomatic systems for the dismantling of the component.
[171] Time threshold is based on estimations and measurements at two recycling plants. This value should be considered as indicative of current practises. However the setting of the threshold requires additional research based also on the analysis of workers health and safety issues.

- The ‘shredding based scenario’ is instead based on the potential mechanical treatments that the TV could undergo in the next future (according to treatments in Table 68).

In order to estimate the benefits of the above requirements at the product level, it is here assumed that thanks to enforcement of the potential requirements, the case-study LCD-TV is dismantled (according to the ‘disassembly scenario’) instead being mechanically shredded and sorted (according to the ‘shredding-based’ scenario).

As discussed in Section 7.5, the treatments in line with the current EoL scenario grant much higher recycling rates of precious metals in PCBs, higher recycling rate of plastic parts (in particular the PMMA board) and of internal electrical cables (otherwise lost in the residues), slightly higher recycling rates of large aluminium and steel parts. Analogously to the WMs case-studies, it is assumed that the selective disassembly and sorting of PCBs allow larger recycling rates of some metals compared to the unsorted shredding of PCBs with other product’s parts.

Table 69 illustrates the recycling rates for different metals (copper, gold, silver and platinum group metals) in the two considered scenarios and the difference in recycled masses.

Table 69 Comparison of recycled mass in two scenarios related to the requirement on disassemblability of key parts

	copper (in PCBs)	silver (in PCBs)	gold (in PCBs)	palladium (in PCBs)	platinum (in PCBs)	steel parts	aluminium parts	PMMA	ABS (frames)	internal cables (copper)
Total mass per device [g / TV]	1.3E+02	5.4E-01	2.0E-01	4.3E-02	2.4E-03	1.9E+03	3.8E+02	1.6E+03	1.5E+03	2.5E+01
A. Recycling rates in the 'disassembly scenario' [%]	95%	92%	97%	99%	99%	95%	95%	94%	94%	24%
B. Recycled masses in the 'disassembly scenario' [g]	125.42	0.49	0.20	0.042	0.0023	1777.45	363.85	1471.10	1419.4	6
C. Recycling rates in 'shredding-based scenario' [%]	60%	11.5%	25.6%	25.6%	25.6%	94%	91%	0%	74%	0%
D. Recycled masses in 'shredding-based scenario' [g]	79.21	0.062	0.052	0.011	0.0006	1758.74	348.53	0	1117	0
Differences of recycled masses (B-D) [g]	**46.2**	**0.43**	**0.15**	**0.031**	**0.0017**	**18.7**	**15.3**	**1471.1**	**302**	**6**

In addition to the previous figures, also further benefits should be considered:

- The case-study LCD-TV contains 8 mg of mercury. This could be partially separated and specifically treated during the shredding-based scenario. This treatments would imply some mass losses in the plant and in the residues (no data are available);

- The shredding-based scenario includes also the production of wastewaters contaminated by mercury that have to be accounted (no data are available about possible impacts of this further treatment);

- The case-study LCD-TV contains some CRMs (estimated in 48.2 mg in the LCD screen and 5.8 mg of rare earths in the lamps). These materials are currently sorted and landfilled. However there are evidences of technological progresses for their recycling. However the shredding-based scenario does not allow their sorting and therefore is not compatible with future recycling technologies.

c. Calculation of the environmental benefits at the product group level

In order to calculate the environmental benefits at the product level it necessary first to estimate the total number of LCD-TV currently produced in the EU and that will be wasted at their EoL.

According to the preparatory study for implementing measures for televisions [IZM, 2007], the estimated number of LCD-TVs sold in the EU for 2010 and their shares (among different size typologies) are shown in Table 70 [IZM, 2007].

Table 70 Estimation of the number and shares of LCD-TV sold in EU-25 for 2010 [IZM, 2007]

	Share [%]	Number of devices
LCD (14" - 26")	22%	5,695,580
LCD (27" - 39")	53%	13,721,170
LCD (40" - 70")	25%	6,472,250
Total number LCD-TV (2010)		25,889,000

Table 71 Average masses of LCD-TVs of different sizes [IZM, 2007]

Average mass of devices with different sizes [kg / TV]	
LCD 32"	7.2
LCD 37"	11.5
LCD 42"	11.8

The differences of recycled masses per devices have been previously calculated for a 20'' TV. However some adjustments factors are needed, in order to consider the different masses of the TV. 0 shows some average masses of LCD-TV with different sizes. According to such values, previous figures of number of LCD in EU for 2010 have been scaled, proportionally to the masses of devices, with the following factors:

- LCD (size: 14" - 26"): scaling factor = 1;
- LCD (size: 27" - 39"): scaling factor = 1.3;
- LCD (size: 40" - 70"): scaling factor = 1.64;

Afterwards, it is necessary to assess what share of these TVs would be fully disassembled instead that shredded thanks to the improved disassemblability of key components. As discussed in the dynamic analysis of section 7.5, it is assumed that the requirements on the disassemblability could affect the evolution on the EoL scenarios, making the disassembly scenario more economically competitive. The analysis is performed in the three situations (situation A, B and C) of evolution of the EoL scenarios as in section 7.5.

The benefits due to the application of the previous requirements, in the different situations, are illustrated in Table 72. Afterwards the Table 73 illustrates the estimated environmental benefits (absolute and normalized values[172]) due to the implementation of potential requirements on disassemblability of key components in the LCD-TV.

[172] Normalization is here referred to the overall environmental impacts of the EU-27 for all the economic sectors. Normalization factor those of Table 11, used for the "high level analysis of the impacts of materials" in Chapter 1.

Table 72 Benefits in terms of additional recycled masses in the different situations

Material	X. Benefits in term of additional recycled mass (compared to situation A)		Y. Overall amount of materials used in the LCD-TVs [10^3 kg/year]	Z. Overall amount of materials used in the EU [10^3 kg/year]	Fraction of the additional recycled material compared to the uses in LCD-TVs (X / Y) [%]		Fraction of the additional recycled material compared to the overall uses in the EU (X / Z) [%]	
	Situation B [10^3 kg/year]	Situation C [10^3 kg/year]			Situation B [%]	Situation C [%]	Situation B [%]	Situation C [%]
Steel	128	256	73,143	79,926,821	0.2%	0.3%	0.00016%	0.00032%
Aluminium	104.7	209.4	13,090	5,020,336	0.8%	1.6%	0.002%	0.004%
PMMA	10,055	20,111	53,487	180,002	18.8%	37.6%	5.6%	11.2%
ABS	2,064.3	4,128.5	51,607	752,039	4.0%	8.0%	0.27%	0.55%
Copper	357	714	5,701	3,525,913	6.3%	12.5%	0.01%	0.02%
Silver	2.94	5.89	18.3	12,050	16.1%	32.2%	0.024%	0.049%
Gold	1.0	2.0	7.0	130	14.3%	28.6%	0.77%	1.53%
Palladium	0.214	0.429	1.5	720	14.7%	29.4%	0.03%	0.06%
Platinum	0.012	0.024						

Table 73 Environmental benefits related to the implementation of potential ecodesign requirements for the disassemblability of the key components of LCD-TV (absolute and normalized values)

		Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutrophication freshwater	Eutrophication marine	Human toxicirty	Aquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
		GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP el.	ADP fossil
		kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Situation B	Environemntal benefits	9.4E+07	3.1E+06	5.3E+05	2.2E+00	6.0E+05	7.6E+04	1.4E+05	1.8E+08	5.8E+06	1.7E+06	6.3E+04	1.5E+09
	Normalized benefits (LCD products)	*0.4%*	*1.7%*	*1.0%*	*0.0%*	*1.5%*	*1.2%*	*0.9%*	*3.8%*	*4.5%*	*3.3%*	*14.0%*	*0.6%*
	Normalized benefits (EU27)	*0.002%*	*0.01%*	*0.002%*	*0%*	*0.007%*	*0.02%*	*0.0024%*	*0.53%*	*0.001%*	*0.0036%*	*0.08%*	*0.005%*
Situation C	Environemntal benefits	1.9E+08	6.2E+06	1.1E+06	4.4E+00	1.2E+06	1.5E+05	2.8E+05	3.6E+08	1.2E+07	3.4E+06	1.3E+05	2.9E+09
	Normalized benefits (LCD products)	*0.9%*	*3.4%*	*2.0%*	*0.1%*	*3.0%*	*2.5%*	*1.7%*	*7.6%*	*9.0%*	*6.6%*	*27.9%*	*1.3%*
	Normalized benefits (EU27)	*0.004%*	*0.02%*	*0.004%*	*0%*	*0.015%*	*0.04%*	*0.0048%*	*1.07%*	*0.002%*	*0.007%*	*0.15%*	*0.01%*

Additional benefits related to the implementation of the requirements should be also considered, including:

- minor losses of mercury in manual disassembly compared to the shredding-based scenario (not estimated because of lacking of information of performances of mechanical plants for the treatment of the LCD-TV)
- possibility to sort fluorescent dusts from lamps, rich in rare earths, and to address them to specific plants for the recycling of such elements (not estimated because of lacking of information about efficiency of plants for the recycling of rare earths from lamps)
- possibility to sort LCD-screen, rich indium, for the potential future recycling of such element (not estimated because of lacking of large-scale plants for the recycling of indium).

7.6.2 Declaration of the content of indium in LCD-TVs

a. Identification of the requirements

LCD has been recognised one of the key parts for the recyclability index (recycling rate: 0%[IEC/TR 62635, 2012]. According to recyclers, one of the reasons of not recycling LCD is the low availability of information about its content in relevant materials. In particular LCD is rich in indium, one of the Critical Raw Material Initiative as identified by the EC studies [EC, 2010]. Indium is important for many emerging technologies, including thin-layer photovoltaic cells, flat displays and white LEDs. The demand for indium in these applications is expected to increase by a factor of eight until 2030. Therefore the potential recycling of this substance at the EoL of LCD-TV is a relevant issue.

Currently no economically viable technology for the recycling of the indium from LCD is available, although various laboratory tests and experimental plants have been developed. As underlined by some European recyclers, various problems hamper the development of large scale plants for the recycling of indium including:

- It is not known quantity of indium in LCD, nor its chemical status, and the content of other substances that could interfere with the recycling;
- Experiences in traditional mining and refining industry are generally not applicable, being that critical raw materials in product's parts are in forms not present in nature (complex mixtures of different metals with glass, plastics and other chemical compounds)
- it is not clear yet if and how recycled materials would be suitable for new manufacturing, nor the quality requirements of input materials by manufacturing companies (e.g. physical/chemical status of input materials, level of purity, etc.)
- Price fluctuations can interfere with recycling activities especially (high risk of investment for development of new plants). In particular, it price of indium almost halved in the last 5 years and it has been assessed that recycling of indium would not be economically viable at the current prices [Holmes, 2010].

The collection of information about the quantity of indium in LCD can contribute to the development of recycling technologies, being essential for recyclers to know the exact amounts of substances potentially recoverable. In particular the declaration of CRMs in the product's parts can contribute significantly to the development of European databases for CRMs in products. Recyclers should have access to such databases in order to proactively develop/improve technologies for the recycling of CRMs.

A potential declarative requirement is following illustrated[173].

[173] Additional information could be also set in the requirement according to other potentially relevant information to be identified according to suggestions from manufacturers and recyclers.

Potential Requirement: Declaration of the content of Indium in LCD-TV

Manufacturer should declare the content of indium in the LCD-TV.

Verification:

Manufacturer shall provide a declaration to the market surveillance authority accompanied, on request, by laboratory tests proving the declared quantity.

For the enforcement of the requirements some additional guidance on the measurement should be se, including, for example, the testing methods for the measurement of the content of indium and how this information should be communicated.

b. Calculation of the environmental benefits at the product group level

As previously observed, flows of indium in the LCD-TV product category are very relevant. It is estimated that 74% of all the indium consumed in the EU-27 is embedded in flat display panels [EC, 2010].

The potential requirement on the declaration of the indium in LCD is also synergic with the potential requirement on the disassemblability of the screen. However, as previously observed, it is not possible to estimate quantitatively the potential environmental benefits achievable, because:

- technologies for recycling of indium from LCD are not fully developed
- environmental impacts of recycling of indium are unknown
- it is still under study if recycled indium could be suitable for the manufacturing of new LCD or other devices

However the potential requirement on the declaration of indium content is intended to contribute to the estimations of flows of such element (current and future) and the assessment of its demand over the time.

It is also highlighted that other potentially relevant information could be provided by manufacturers jointly with the declaration of the indium content (e.g. about the chemical and physical status of indium compounds in the LCD and the content of other substances that could interfere with the recycling). However this information should be identified by recyclers and manufacturers according to the current development of emerging recycling technologies.

7.6.3 Improvement of the recyclability of plastics in the product

a. Identification of the requirements

As previously discussed in section 7.6, plastic parts are some of the relevant components of the case-study LCD-TV because of their mass in the product BOM, their environmental impacts and the specific disassembly treatments that they require to be sorted and recycled.

The most relevant plastic parts are the PMMA board and plastic frames (in ABS), and to a lower extent the plastic foils (light guides). The potential recycling of PMMA and ABS in the LCD-TV case-study can reduce from 2% to 4% the above mentioned life-cycle impacts (according to the Recyclability Benefit rates in section 7.4.2.3).

The section 7.6.1 already discussed the recyclability of the PMMA board, by introducing a potential requirement on the disassemblability of the PMMA board and analyzing the potentially related benefits.

According to the analysis of the Recyclability rate index of plastics (discussed in section 7.4.1.3) the recyclability of other plastic parts is instead subjected to two some conditions:

- recyclable plastics are used for the TV's frames (e.g. HI-PS, PP, ABS, ABS-PC)
- recyclable plastics frames do not embed flame retardants and/or fillers[174, 175].

In particular, the presence of flame retardants and/or fillers is not compatible with their separation via mechanical systems (sorting by density)[176]. These plastic parts could be still suitable for recycling if manually disassembled. However, flame retardants are also related to safety requirements of the product, being these substances necessary to reduce the flammability of materials[177].

According to recyclers' experience, manufacturers are reluctant in using recycled plastics embedding flame retardants because:

- flame retardants embedded in the recyclable materials are generally unknown;
- the use of different flame retardants in plastic parts interferes with flame resistance of the materials, making difficult to achieve requirements on the flammability of the product.

It is also highlighted that other characteristics of the plastics, including other additives and the colour, can interfere with the recycling processes.

Some possible strategies to underpin the recyclability of plastics have been identified, based on communication with recyclers. These strategies include:

- improvement of plastic recyclability e.g. by using plastics with higher recycling rates (e.g. in accordance with [IEC/TR 62635, 2012]) and easy to be disassembled;

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[174] To mechanically recycle post-user plastic waste containing brominated flame retardant, it has to be collected, sorted, separated, ground, washed and reprocessed before it can be mixed with virgin plastics of the same type for molding new products, or used on its own for alternative lower value products [BSEF, 2012]. Only in a limited number of cases are the overall plastics recycling operations economically viable because of the relatively low cost of new, virgin plastics.

[175] It is currently observed an intensive research to develop processes for the recycling of plastics with flame retardants. There are some evidences in the scientific literature of technologies for the sorting of plastics with flame retardants, as for example by X-ray fluorescent (XRF) spectroscopy combined with other systems (including Near Infrared Spectroscopy and other techniques), thanks to which different types of flame-retardants (FRs) can be identified and pure resin with FRs can be separated [Di Maio et al., 2010]. However the representativeness of their use in the EU is not available. Data from IEC/TR 62635 have been assumed as the most representative currently available.

[176] This is based on communication of some recyclers and studies in the scientific literature (e.g. [Oakdene Hollins , 2011]). However, according to communications from some recyclers there are evidences of mechanical plants sorting plastics with flame retardants. However, quantitative data about their performances and representativeness in the EU context are not available.

[177] Various standards have been defined for the measurement of the ignition and burning resistance characteristics of materials including also classification of flammability (e.g. [ISO9773, 1998; ISO9772, 2001]).

- easy identification of plastic typologies by marking large plastic parts in accordance with current standard [ISO 11469:2000].
- Identification of fillers and flame retardants in large plastic parts in accordance with current standards [ISO 1043-2, 2011; ISO 1043-4, 1998].

Concerning the marking of plastics it has been observed in the recycling plant that several parts are marked. However the ISO standards do not specify the characteristics of the marking. Therefore the marking is sometimes ineffective and difficult to be identified by recyclers because located in a not accessible position or because the small dimension.

Furthermore, specification of fillers or flame retardants is generally missing. Plastic with flame retardants cannot be currently sorted by mechanical systems and, therefore, they are energy recovered. However, according to some recyclers, homogeneous plastic parts with the same flame retardants could be potentially recycled. An adequate marking including the content of flame retardants (according to ISO 1043-4) could contribute to an increased recyclability of plastics.

On such purpose is highlighted that "*the WEEE Directive requires that plastics containing brominated flame retardants should be separated, which can occur at any point during the recycling process. However, at present there are few commercially viable processes available for this separation, though this has been investigated recently and schemes are coming on line. Therefore the existing practice of mechanical shredding and sorting generates large volumes of mixed plastics, which are often not economically viable to separate fully. […] Where plastics are exported for recycling, anecdotal evidence suggests that flame retardant-containing plastics are separated by hand prior to recycling*" [Oakdene Hollins , 2011]. It is also observed that, if separation of plastics containing brominated flame retardant is implemented specifically, several options for recovery of antimony trioxide are also available [Oakdene Hollins, 2011].

In order to improve the identification and sorting of large plastic parts, the following potential requirement is therefore illustrated.

Potential Requirement: Marking of plastic parts[178]

Manufacturer should mark plastic parts larger than 25 g (other than PMMA board[179]) by specifying the typology of plastic and the content of fillers and flame retardants, according to the standards ISO 11469:2000, ISO 1043-2, 2011 and ISO 1043-4, 1998. For plastic parts over 200g, the marking should be enough large and located in a visible position in order to be easy to be identified by workers[180].

Verification:

Manufacturer shall provide the technical documentation to prove the conformity to the above mentioned ISO standards and the additional technical specifications for the marking (dimension and position).

[178] According to feedback from recyclers, this typology of requirement could include additional specifications as, for example, marking back-cover outside instead than inside.

[179] Due to the required level of transparency, marking of PMMA should be avoided. According to the scientific literature and communication from recyclers, PMMA is currently the material used for the light guide board of LCD-TV. However if other materials were developed and introduced in the products, manufacturers should provide information to recyclers (e.g. by additional internal marking of the product).

[180] Additional specifications about dimensions and position of the marking should be set (including also other potential measures for the improvement of the identification of plastics). However, according to communications from recyclers, this improved marking can be relevant mainly for large plastic parts. The threshold of 200g is, however, indicative and can be refined according to additional information from recyclers.

Mass thresholds of the previous requirements have to be intended as indicative. The setting of the thresholds requires additional investigation.

It is highlighted that "for marking integrated in the moulding process, the costs include only investment costs in either replacing or modifying the moulds. When a mould is being replaced or repaired as part of the regular operation, a mark can be included at almost negligible cost" [EC, 1999]. It is also noticed that verification of plastic marking can be affected by some problems including reliability problems. According to some association of recyclers, a false labelling can damage the production of an entire batch of recycled materials.

It is also underlined that the previous requirements could be extended to other innovative plastic marking systems (e.g. the use of labelling or of tracer substances[181]), once these technologies would be established and economically viable. Also values of recycling rates of plastics (as those in the IEC/TR 62635) should be updated according to the technological development. However, these technologies are currently still at 'research' stage [Bezati, et al., 2011].

To underpin the recyclability of plastics, a potential requirement on the minimum threshold of the Recyclability rate index for plastics in the LCD-TV (as discussed in section 7.5) is also discussed. In order to achieve such threshold, manufacturer should employ plastics more recyclable and easy to be identified and disassembled. The threshold about the recyclability rate of plastics is therefore synergic to the previous potential requirement on plastic marking and disassemblability of key components.

Potential Requirement: Minimum threshold of the Recyclability rate index for plastics of the LCD-TV

The Recyclability rate index for plastics of the LCD-TV shall be higher than 80%[182].

Verification:

Manufacturer shall provide a declaration of the Recyclability rate index of the product with the calculation data-sheets and additional technical documentation, in accordance with guidance documents (Report n° 3).

It is highlighted that the potential requirement on threshold of the Recyclability rate of plastics is largely dependent by the recyclability of the PMMA board. According to the current EoL scenario, the board is assumed to be disassembled and addressed to selective recycling. The PMMA board therefore account for about 40% of Recyclability rate of plastics and this justify high values of the previous threshold.

b. Assessment of the benefits at the case-study product level

The assessment of the benefits at the case-study product level can be made by the comparison of different designed products, after a more in depth market analysis. However the present report focused only on one case-study. In order to illustrate the potential benefits related to the discussed requirements for the recyclability of plastics, it is assumed to compare three example products[183]:

[181] See Section 3.3 for further detail.
[182] This threshold has been set on the basis of the analyzed case-study. However, an extensive analysis of various products in the marked is necessary before the setting of thresholds. Furthermore, thresholds could be differentiated by TV sizes.
[183] The BOM of the three exemplary products have been built in analogy to the analyzed LCD-TV case-study.

- Product A. LCD-TV with a high value of the Recyclability rate of plastics (80%, in compliance with the previous potential threshold requirement). It is assumed that the large plastic parts (other than the PMMA board) are made in ABS without flame retardants and fillers. Furthermore ABS parts are assumed to be clearly marked allowing to be sorted from other plastics and addressed to selective recycling.

- Product B. LCD-TV with a 'medium' value of the Recyclability rate of plastics (about 50%). It is assumed that some large plastic frames are made in ABS without flame retardants and fillers, while other parts (other than the PMMA board)) are made by not recyclable plastics. Large plastic parts are not marked. Therefore these parts are collected together with other plastics and afterwards mechanically separated.

- Product C. LCD-TV with a low value of the Recyclability rate of plastics (about 40%). It is assumed that all the plastic parts (other than the PMMA board) are not recyclable (e.g. because with flame retardants/fillers).

Table 74 illustrates the three exemplary LCD-TVs with different recycling rates of plastics and different values of the Recyclability rate for plastics. It is highlighted that estimations have a large uncertainty due to data availability and the assumed scenario (especially concerning the content of flame retardant and the typology of recycling process they will undergo).

Table 74 Recyclability of exemplary LCD-TV with different plastics

Product A			**Product B**			**Product C**		
Material	**mass [g]**	**Part detail and EoL treatments**	**Material**	**mass [g]**	**Part detail and EoL treatments**	**Material**	**mass [g]**	**Part detail and EoL treatments**
ABS (without flame ret.)	1480	plastic parts marked and easy to be identified (manually sorted). Recycling rate: 94% [IEC/TR 62635, 2012]	ABS (without flame ret.)	450	plastic parts not marked. Separated by mechanical treatments. Recycling rate: 74% [IEC/TR 62635, 2012]	ABS (without flame ret.)	0	
PMMA board	1500	easy to be identified and disassembled (manually sorted). recycling rate: 94% (estimated)	PMMA board	1500	easy to be identified and disassembled (manually sorted). recycling rate: 94% (estimated)	PMMA board	1500	easy to be identified and disassembled (manually sorted). recycling rate: 94% (estimated)
Plastics (not recyclable)	520	Not recycled (Recycling rate: 0%)	Plastics (not recyclable)	1550	Not recycled (Recycling rate: 0%)	Plastics (not recyclable)	2000	Not recycled. Recycling rate: 0%
Total plastics [g]	3500		Total plastics [g]	3500		Total plastics [g]	3500	
Total recyclable plastics [g]	2801.2		Total recyclable plastics [g]	1743		Total recyclable plastics [g]	1410	
Recyclability rate of plastics [%]	*80.0%*		*Recyclability rate of plastics [%]*	*49.8%*		*Recyclability rate of plastics [%]*	*40.3%*	

Afterwards, it is assumed that, thanks to the potential requirements on plastics, LCD-TV would be designed. The environmental benefits of the potential requirements can be therefore estimated in terms of additional amount of recycled plastics.

The benefits for the previous exemplary products are shown in Table 75. It is assumed that Product B and Product C would have additional amount of recyclable plastics in order to achieve the established threshold of recyclability (80%) as for Product A.

Table 75 Benefits per device related to the application of the potential requirements about recyclability of plastics

Benefits related to the application of the potential requirements		
	Product B	Product C
Additional mass of recycled ABS [g/TV]	1000	1480

c. Assessment of the benefits at the product group level

For the estimation of the environmental benefits are the product group it is necessary a detailed analysis of different LCD-TV in the market. Being this out of the scope of the analysis, some assumptions have been here introduced in order to estimate the potential benefits:

- The number of LCD-TVs is as illustrated in Section 7.6.1;
- It is assumed that, among the TVs in the market, one third already accomplish to the Recyclability threshold (as for Product A), one third has a medium Recyclability rate of plastics (as for Product B) and one third has a low Recyclability rate of plastics (as for Product C);
- It is assumed that the TVs with improved recyclability would have large plastic parts made by ABS. Actually, other recyclable plastics could be used (e.g. HI-PS, ABC/PC, PP), but more detailed data are not available for the analysis.
- Life-cycle impacts for the production of primary ABS from database [ELCD, 2010], while impacts of recycled ABS are assumed 24% of primary plastic.

Table 76 Benefits related to the application to the LCD-TV product group of the potential requirements about recyclability of plastics

Benefits for the application of the potential requirements		
Additional mass of recycled ABS [10^6 kg]	Use of ABS in EU [10^6 kg]	Fraction [%]
28.3	752.0	3.8%

Table 77 Environmental benefits (absolute and normalized) related to the application to the LCD-TV product group of the potential requirements about recyclability of plastics

	Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutroph. freshwater	Eutroph. marine	Human toxicirty	Aquatic ecotox.	Terrestric ecotox.	Abiotic Depl. - element	Abiotic Depl.- fossil
	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil
	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
Environemntal benefits	8.4E+07	2.7E+05	1.5E+05	8.4E-02	6.2E+04	3.6E+04	5.6E+04	2.5E+06	6.4E+04	1.1E+05	3.3E+01	1.9E+09
Normalized benefits (LCD products)	*0.4%*	*0.1%*	*0.3%*	*0%*	*0.2%*	*0.6%*	*0.3%*	*0.1%*	*0.05%*	*0.2%*	*0.01%*	*0.8%*
Normalized benefits (EU27)	*0.002%*	*0.001%*	*0.001%*	*0%*	*0.001%*	*0.01%*	*0.001%*	*0.007%*	*0.00001%*	*0.0002%*	*0.00004%*	*0.006%*

It is highlighted that the previous benefits are estimated based on the current EoL scenario, which assumes that the PMMA boards are addressed to selective recycling (estimated recycling rate: 94%). However, as discussed in section 7.6, the potential dynamic evolution of EoL scenarios is expected to move towards an increased rate of the shredding-based EoL treatments of LCD-TV. In this new EoL scenario the previous potential requirements on the threshold of the Recyclability rate for plastic would have also the effect to underpin the recycling of PMMA, with overall environmental benefits higher than those illustrated in Table 77.

7.6.4 Comparison of potential environmental benefits

In order to assess the relevance of potential requirements previously discussed, previous figures concerning the estimated benefits have been compared to the estimated benefits that derive from the ecodesign implementing measures for the "Television" product group already adopted by the EU [EC 2010b].

According to estimations, the implementing measures will grant the yearly saving of 28 TWh (end-use electricity in 2020)[184]. Life cycle benefits related to this amount of saving have been calculated according to average life-cycle inventory of average 1 kWh of electricity in the EU27 [ELCD, 2010].

The benefits of this EU implementing measures for Televisions have been afterwards compared with estimated benefits related to the potential requirements on resource efficiency for "LCD-TV"[185] (improved recyclability of plastics and disassemblability of key parts – average among scenarios "B" and "C") previously discussed. Results are illustrated in Table 78.

Table 78 Comparison of the environmental benefits related to the adoption of Ecodesign implementing measures on Television with potential requirements on resource efficiency

A. Total potential benefits due to 2 potential requirements on resource efficiency											
Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutroph. freshwater	Eutroph. marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
2.3E+08	4.9E+06	9.4E+05	3.4E+00	9.6E+05	1.5E+05	2.7E+05	2.7E+08	8.8E+06	2.7E+06	9.4E+04	4.1E+09
B. Total life-cycle benefits related to requirements on resource efficiency of Televisions (28 TWh of electricity saved)											
Climate change	Acidification	Photochemical oxidant	Ozone depletion	Respiratory effects	Eutroph. freshwater	Eutroph. marine	Human toxicirty	Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depl. - element	Abiotic Depl.- fossil
kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ
1.7E+10	1.3E+08	3.8E+07	4.0E+03	2.8E+07	4.2E+06	1.2E+07	1.4E+09	4.6E+07	2.2E+07	1.1E+03	1.7E+11
Ratio (A / B) [%]											
1.4%	3.9%	2.5%	0.1%	3.5%	3.6%	2.3%	19%	19%	12%	8472%	2.4%

It is possible to observe that the benefits generally range between 1.4% and 3.6% of benefits of implementing measures for several impact categories. More relevant ratios (from 10% to 20%) are estimated for the Human toxicity and Ecotoxicity impacts. Potential benefits due to requirements for resource efficiency for the "Abiotic Depletion Potential element" are much higher: this is due to the low incidence of electricity savings for this impact category. Finally benefits for the Ozone Depletion impact category are negligible.

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[184] European Commission. DG Enterprise and Industry website (http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm; access September 2012).

[185] It is highlighted that the Ecodesign implementing measures refer to the whole 'Television' product group while the potential requirements on resource efficiency refer to the LCD-TVs only.

7.7 Summary and conclusions on the case-study analysis

Results of the assessments

The application of the project's methods on one LCD-TV case study based on data from the literature and information from recyclers brought the following results:

- The calculation of the RRR Benefits rates (including calculation of life-cycle impacts of the product) has been performed. The analysis showed that the manufacturing of some components is relevant for some impact categories. For example the manufacturing of PCBs dominates the ADP-element impact category, and it is relevant for others (e.g. Human toxicity, Aquatic Ecotoxicity and Terrestric ecotoxicity). It is highlighted that the energy consumption during the use phase is based on data from the technical specifications of the product. However, these data refer to a product that reached its EoL and, therefore, energy consumption during the use phase could be overestimated and not in line with the consumption of modern devices. Actually, the assumption of lower consumption during the use phase would indeed change the results and would bring much higher significance of impacts during the other life cycle stages. It is highlighted that:
    - The assumed EoL grants high values of the Recyclability index, due to the carefully sorting of lamps, LCD, metals (ferrous and non-ferrous), electronics and plastics.
    - The Recyclability index is largely influenced by large plastic parts and, in particular, plastic framework and light guide board (in PMMA). The recyclability index for plastics has been therefore analyzed. The board is made by high quality PMMA, which can be recycled only if manually disassembled. Plastic frameworks can be recycled if made by recyclable plastics without any flame retardants and/or fillers. Unfortunately, no data were available about the content of flame retardants in the case-study.
    - Reusability and energy recoverability are not relevant for the case-study
    - Recyclability Benefits rates is over 90% for ADP-elements and over 50% for human toxicity, and around 40% for aquatic and terrestric ecotoxicity.

Identified products "hot spots"

Based on the previous results, the following conclusions have been drafted:

- Backlight fluorescent lamps are relevant components for the content of hazardous substances (mercury). Lamps are also potentially relevant for the content of CRMs (various rare earths in the fluorescent dusts).
- LCD screen is very relevant for the content of CRM (indium). It also contributes up to 2 % for some impact categories it can embed some hazardous substances (heavy metals).

- Plastic parts represent about 50% of the mass of the studied LCD-TV. Furthermore, they contribute from 2% to 5% to several impacts categories (e.g. Terrestric ecotoxicity, GWP, Abiotic Depletion – fossil, Freshwater Aquatic Ecotoxicity and Freshwater Eutrophication).

- Lamps and LCD are rich in CRMs. However their recycling is still under research and development. For rare earths in lamps, some exemplary treatments have been observed in recycling plants, while the recycling of indium and other metals in LCD is still at an early stage of development. However, as underlined by recyclers, further information about their content in the TV's parts is necessary before investing in the development of large scale recycling plants. Furthermore, the recycling of indium and rare earth in these components is possible only if these are manually separated (not compatible instead with a potential shredding-based EoL scenario).

- Parts made of polymers are relevant: manual sorting of plastics allows high recyclability of the product. In particular mechanical systems do not allow the separation of PMMA and of plastics with flame retardants. An efficient marking of plastic parts could contribute to the increase the recyclability of the product.

Potential products requirements and associated benefits

In order to grant in the future high EoL performances of the LCD-TV, some potentially relevant ecodesign requirements have been derived from the assessment:

- *improved disassemblability of key parts* (PCBs, lamps, LCD screen, PMMA board). This would allow to reduce costs for disassembly and to make the disassembly-based EoL scenario economically more competitive.

- *declaration of the content of indium in LCD*. This declaration is intended to contribute to the estimations of flows of such element (current and future) and the assessment of its demand over the time

- *improved marking of large plastic parts* (according to ISO 11469 and 1042-2 standards), in which marking is clearly visible and easy to be located. This would allow current recyclers to sort recyclable plastics from non-recyclable ones. Furthermore, plastic with flame retardants cannot be sorted by mechanical systems and, therefore, they are currently energy recovered. However, according to some recyclers, homogeneous plastic parts with the same flame retardants could be potentially recycled. An adequate marking including the content of flame retardants (according to ISO 1043-4) could contribute to an increased recyclability of plastics.

- *threshold of the Recyclability rate for plastics* (measured according to guidance documents in the Report n° 3). This potential requirement would underpin the use of more recyclable plastics in the product. An exemplary threshold of 80% has been discussed. However, an extensive analysis of various products in the marked is necessary before the setting of thresholds. Furthermore, thresholds could be differentiated by TV sizes

Such requirements could produce the following potential environmental benefits:

- the improved disassemblability of key parts could contribute to maintain the high amount of PCBs manually separated (with large recovery of some relevant materials), to reduce the risk of contamination by mercury and other heavy metals (in lamps and LCD), and allow high recycling rate of plastic parts (PMMA board). It is estimated that these requirements would allow in the EU27 a reduction up to 1% of the human toxicity impact, up to 0.15% reduction of the ADP-element impact, and the recycling from 5% to 11% of the overall PMMA consumed. The improved disassemblability of lamps and LCD is also an essential condition for the future development of treatments for the recycling of CRMs they are embedding. It is here highlighter that the presented normalized values concerns EU27 (including all the productive sectors). However, the normalization could be different, focusing for example on the specific product group (washing machines) or some product groups (e.g. ErP).

- Future innovative TV sets could use mercury-free systems for lighting. In this case, requirement on disassemblability of fluorescent lamps would be not relevant. However the typology of requirements on disassemblability is still valid for any other potentially relevant substance and resource (if present in products).

- the declaration of the content of indium in LCD can contribute significantly to the development of European databases for CRMs in products. Recyclers should have access to such databases in order to proactively develop/improve technologies for the recycling of CRMs. If identified relevant by recyclers, also other additional information should be declared including, for example, the physical/chemical status of indium compounds and the content of other substances that could interfere with the recycling

- the potential requirements on recyclability of plastics (plastic marking and threshold of the recyclability rate) can contribute to increase the recyclability of plastics in LCD-TV. It is estimated that the requirement could contribute to the additional recycling of about 750 10^6 kg of ABS (around 4% of the EU uses) and a reduction of the EU energy consumption of 0.01%. It is highlighted that the content of flame retardant in the case-study was not available. Estimated potential environmental benefits should be revised based on more detailed information about the TV’s BOM.

Conclusions

The present report applied the project methods to some exemplary products in order to test their applicability, their relevance and usefulness at the product level and to draw some recommendations at the method level.

The analysis has been preceded by a ‘high level environmental assessment’ consisting of a review of studies in the scientific literature and a further analysis of flows of materials within the EU-27 to identify relevant materials for their environmental impacts within the EU-27. From this analysis it was possible to identify the following materials:

- *in terms of specific impacts per unit of mass*: all the considered precious metals (such as gold, silver and platinum group), several EU critical raw materials (e.g. platinum, tantalum, gallium, magnesium, cobalt, indium, rare earths) and various commonly used material (such as copper, chromium, molybdenum, nickel).
- *in terms of overall impact in the EU-27*: copper, various precious metals and some common metals (such as iron, aluminium, magnesium, chromium and zinc). Among plastics, PUR, PE-HD and PP were the most relevant.

The ‘high level environmental assessment’ has been the basis for the selection of three case-studies, potentially relevant for the project scopes, namely:

- the ‘imaging equipment’ product group (limited to the analysis of the recycled content)
- the ‘washing machine - WM’ product group (for the analysis of RRR, use of relevant resources, use of hazardous substances and durability)
- the ‘LCD-TV’ product group (for the analysis of RRR, use of relevant resources and use of hazardous substances).

The outcomes of the ‘high level environmental assessment’ have also been used to identify relevant materials (including some EU Critical Raw Materials) embedded in the case-study products and their EoL treatments (with special focus on their recyclability) and to assess the potential benefits which could be achieved by setting some potential product requirements.

After this preliminary analysis, the project methods have been applied to the selected case-studies. Concerning the developed methods, the following conclusions can be drawn:

- The methods are applicable to the exemplary products with available data.
- It is possible to analyze the performance of products on the basis of the various indices such as: RRR rate (including RRR for plastics and/or CRMs) RRR Benefit rates, Recycled content, Recycled content Benefits, presence of hazardous substances into components;
- The definition of representative EoL scenario(s) represents a key step of the methods. This definition requires a detailed analysis of current EoL treatments at the EU level, to be based on information from recyclers and manufacturer. Also a dynamic analysis of future scenarios can be relevant, especially when there is evidence for changes to the EoL scenario(s) in the near future, for example, due to economic reasons and/or technological evolution.

- The key role or current/future EoL scenario and the steps for its definition have been stressed in the revision of the project methods (report n° 3) and they represent an advancement compared to the recommendations of the IEC/TR 62635.

The outcomes from the application of the methods can be used to identify and assess potentially relevant requirements. To this end, a procedure has been illustrated and discussed. The procedure combines the calculation of the various indices (see methods presented in Report n° 3) to a selected product group, first to identify 'hot spots' (key components and/or product parameters that are relevant in terms of relevant life-cycle impacts and/or improvement potential) and afterwards to assess, among the typologies of requirements previously defined, those that could produce relevant environmental benefits (both at the case-study product level and at the product group level). The procedure also uses the typologies of product requirements that have been identified as suitable for the analysis. This list has been provided in Chapter 3 and was based on a survey and analysis of criteria from the EU Ecolabel scheme and various publications from the scientific literature.

From the analysis of the case-studies, the following conclusions have been drawn:

- '*imaging equipment' case-study*:
    - o the product is largely composed of plastic parts (about 50%). Furthermore, energy consumption for the production and manufacturing of such plastic parts is very relevant (accounting for about 50%-60% of the global life-cycle energy requirement – GER, based on two different scenarios considered for the 'use phase'). These are the two main conditions for the potential relevance of introducing recycled materials in the product's manufacturing.
    - o Environmental benefits from the use of recycled materials are relevant in a life-cycle perspective for the energy consumption. For example, it could be possible to achieve relevant reductions (up to 10%) of the product's GER by using recycled plastics in the product manufacturing. In particular, with a 10% recycled content of plastics in the product a reduction of the GER of around 3.5% is achieved. With a recycled content of 30% the decrease in the GER is around 10.5%.
    - o These figures have been used to set potential requirements on the thresholds of 'recycled content' of plastic parts in the products. The enforcement of requirements on recycled content thresholds could be anticipated by declarative requirements. However, the definition of such requirements would require a more comprehensive market analysis (including different products) and more detailed life-cycle inventory data for the recycled plastics. In addition, the setting of this potential requirement should also follow a more comprehensive market analysis, to assess the availability of recycled plastics for the manufacturing and technical feasibility of using recycled plastics in the product.
    - o Finally the verification of requirements concerning the recycled content is a key issue, based on a declaration of the manufacturer supported by technical documentation[186].
- *'Washing machine' case-study*:
    - o Two main EoL scenarios have been identified for the product group: 1) one scenario is based on pre-dismantling plus some mechanical treatments and sorting; 2) the other scenario is

[186] For further detail on the verification see Report n° 3 – Chapter 3.

largely based on various shredding phases (with hand picking of relevant parts) followed by automatic sorting.

- The performances of the two case-studies for WMs are largely different for various indices (mainly the RRR rates and RRR benefits rates). This is due to different material used (e.g. counterweights in concrete or cast-iron) and the different recycling rate of some materials (mainly the recycling rates of precious metals).
- Some relevant losses of copper and precious metals in the PCBs have been observed and some losses of metals (copper, steel and rare earths) in the motor.
- It has been also observed that new WMs currently introduced in the market sometimes embody LCD screens. All the interviewed recyclers agreed that LCDs in WMs have to be preventively extracted to avoid potentially contaminating other fractions (for example PCBs without LCD) causing a potential downcycling of recyclable resources.
- In order to improve the EoL performances of the WM, three potentially relevant ecodesign requirements have been derived from the assessment:
  - Firstly the improved disassemblability of PCBs would allow a large amount of PCBs to be preventively manually dismantled (instead of being shredded) with higher recycling rates for copper, gold, silver, and PGMs.
  - Secondly the improved disassemblability of motors would allow a larger recycling rate (+5%) of embodied metals (steel and copper). Furthermore, this requirement would be essential for the separation of neodymium magnets (when embodied), once commercial recycling routes of rare earths would be established.
  - Finally the improved disassemblability of LCD screens would allow an easier separation of the LCD, reducing the risks of contamination of other recyclable parts.

- *'LCD-TV' case-study*:
  - The current EoL treatments for LCD-TVs are based on a full manual dismantling of the devices. This current EoL scenario allows high values of the RRR and RRR benefits rates;
  - Currently, there is evidence of intensive research to move towards scenarios based on mechanical processing (pre-shredding and shredding with manual/mechanical sorting). However these new scenarios are still at exemplary testing stages and are hindered by some problems, mainly due to the treatments for the reduction of releases into the environment of mercury from fluorescent lamps.
  - The analysis of a case-study of LCD-TVs demonstrated that the manufacturing of some components is relevant for some impact categories. For example the manufacturing of PCBs dominates the ADP-element impact category, and it is relevant for others (e.g. Human toxicity, Aquatic Ecotoxicity and Terrestric ecotoxicity). The LCD screen is very relevant for the content of CRM (indium). Plastic parts represent about 50% of the mass of the studied LCD-TV. Furthermore, they contribute from 2% to 5% for several impacts categories. Backlight fluorescent lamps are relevant components for the content of hazardous substances (mercury).

Lamps are also potentially relevant for the content of CRMs (various rare earths in the fluorescent dusts).

- o In order to permit high EoL performances for LCD-TVs in the future, some potentially relevant ecodesign requirements have been derived from the assessment. Firstly the improved disassemblability of key parts (PCBs, lamps, LCD screen, PMMA board) is discussed. This would allow reductions in the costs of disassembly and would make the disassembly-based EoL scenario more economically competitive in the future. These requirements could be separately enforced or, otherwise, cumulative requirements (for two or more key parts) could be set. Decisions among different alternative should be based on a more extensive analysis of product in the market.
- o Afterwards, a declaration of the content of indium in LCD is proposed as a requirement. This declaration is intended to contribute to the estimations of flows of this element (current and future) and the assessment of its demand over time.
- o Another requirement is based on the improved marking of large plastic parts (according to ISO 11469 and 1042-2 standards), in which marking is clearly visible and easy to be located. This would allow current recyclers to sort recyclable plastics from non-recyclable ones. Furthermore, an adequate marking including the content of flame retardants (according to ISO 1043-4) could contribute to an increased recyclability of plastics.
- o Finally, a potential requirement of a threshold of the Recyclability rate for plastics is discussed. This requirement would underpin the use of more recyclable plastics in the product. An exemplary threshold of 80% has been discussed. However, an extensive analysis of various products in the market is necessary before the setting of thresholds (to be potentially differentiated by TV dimensions).

As general remarks on the requirements it is observed that:

- The analysis performed here was mostly exemplary and applied to some case-study products. However, a more comprehensive analysis of products representative of the market would be beneficial to run the methods: this would lead to a more precise definition of the requirements and the assessments of their benefits (especially for the assessment at the high level)
- The enforcement and verification of requirements would usefully be supported as far as possible by standard. For example technical standards under development (e.g. the IEC/TR 62635) could support the enforcement of requirements based on the RRR rates, while standards to be developed (e.g. the standard for the EoL treatment of products, or procedures for the measurement of dismantling time) could be used for the setting of the EoL scenario (for e.g. the RRR and RRR benefit rates) and the requirements on the disassemblability of key parts. It would be desirable for a mandate to Standardisation Organisations to be issued on for the relevant standards as soon as possible.

Finally, as a general remark on the application of the methods, it is highlighted that all the methods could be integrated in the future into existing tools used in policies (e.g. MEErP ecoreport tool), although some adaptation work has to be done.

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References

[ADEME, 2008] ADEME - Agence de l'Environnement et de la Maîtrise de l'Energie. Etat de l'art des Technologies de Recyclage de Certains DEEE : PAM, Tubes Cathodiques, Cartes et Composants Electroniques. Rapport Final. Novembre 2008. (in French).

[Allwood et al., 2011] Allwood, J.M., Cullen, J.M., Carruth, M., Milford, R.L., Patel, A.C.H., Moynihan, M., Cooper, D.R., McBrien, M., Going on a metal diet – Using less liquid metal to deliver the same services in order to save energy and carbon. University of Cambridge. 2011 (http://www.lcmp.eng.cam.ac.uk/wellmet2/publications)

[Bertram et al., 2002] M. Bertram, T.E. Graedel, H. Rechberger, S. Spatari. "The contemporary European copper cycle: waste management subsystem". Ecological Economics 42 (2002) 43–57.

[Bezati et al., 2011] F. Bezati, D. Froelich, V. Massardier, E. Maris. "Addition of X-ray fluorescent tracers into polymers, new technology for automatic sorting of plastics: Proposal for selecting some relevant tracers". Resources, Conservation and Recycling 55 (2011) 1214– 1221

[BGS, 2011] British Geological Survey - European Mineral Statistics '2005-2009'.

[Boothroyd et Alting, 1992] G. Bothered, L. Alting. Design for Assembly and Disassembly. CIRP Annals - Manufacturing Technology. Volume 41, Issue 2, 1992, Pages 625–636

[Brennan et al., 2002] Brennan, L. B., Isaac, D. H. and Arnold, J. C. (2002), Recycling of acrylonitrile–butadiene–styrene and high-impact polystyrene from waste computer equipment. Journal of Applied Polymer Science, 86: 572–578.

[Brezet and van Hemel, 1997] Brezet H and van Hemel C. "Ecodesign: a promising approach to sustainable production and consumption", 1997. United Nations Environment Programme (UNEP).

[Brusselaers et al., 2006] Brusselaers, F.E. Mark, L. Tange. A Technical Report Produced by Plastics Europe in Cooperation with Umicore and EFRA: Using Metal-RichWEEEPlastics as Feedstock/FuelSubstitute for an IntegratedMetalsSmelter. (2006) www.plasticseurope.org

[BSEF, 2012] Bromine Science and Environmental Forum (BSEF). Website (access on September 2012) www.bsef.com/science/brominated-flame-retardants-and-recycling/technical-recycling-and-waste-solutions#mechanical

[BUWAL, 1996] Dokumentationsdienst Schriftenreihe Umwelt Nr.250, Ökoinventare für Verpackungen Bundesamt für Umwelt, Wald und Landschaft (BUWAL), as provided by the GaBi databases.

[Carlin, 2000] J. F. Carlin. Antimony Recycling in the United States in 2000. U.S. Geological Survey. 2000.

[Castro et al., 2004] M.B. Castro, J.A.M. Remmerswaal, J.C. Brezet, A. van Schaik, M.A. Reuter. A simulation model of the comminution–liberation of recycling streams Relationships between product design and the liberation of materials during recycling. Int. J. Miner. Process. 75 (2005) 255– 281.

[Chancerel et al., 2009] P. Chancerel, C. E.M. Meskers, C. Hageluken, and V. S. Rotter. Assessment of Precious Metal Flows During Preprocessing of Waste Electrical and Electronic Equipment. Journal of Industrial Ecology. Volume 13, Number 5.

[Chiodo et al, 1998] Chiodo, J.D., Billet,E., Harrisson,D., Active disassembly. Journal of Sustainable Product Design, 1998(7): p. pp.26-36.

[Dewulf et al., 2001] Dewulf, W., Duflou,J., Anders, A., Integrating eco-efficiency in rail vehicle design - Final report of the RAVEL Project. 2001, Leuven (Belgium): Leuven University Press. ISBN 90-5867-176-3.

[DFA, 2012] Design for manufacture and Assembly (DFA). From website: http://www.dfma.com/ (access on July 2012).

[Di Maio et al., 2010] F. Di Maio, P. Rem, B. Hu, S. Serranti and G. Bonifazi. The W2Plastics Project: Exploring the Limits of Polymer Separation. The Open Waste Management Journal, 2010, 3, 90-98.

[Dowie, 1995] Dowie, T.A., A disassembly planning and optimisation methodology for design, in Department of Mechanical Engineering, Design and Manufacture. PhD thesis. 1995, Manchester Metropolitan University: Manchester (United Kingdom). p. 167p.

[Du et Graedel, 2011] X. Du, T. E. Graedel. Global Rare Earth In-Use Stocks in NdFeB Permanent Magnets. Journal of Industrial Ecology. Volume 15, Issue 6, pages 836–843, December 2011.

[Duflou et al., 2006] Duflou, J., Willems,B., Dewulf,W., Towards self disassembling products - Design solutions for economically feasible large-scale disassembly, in Innovation in Life cycle Engineering and Sustainable development, D. Brissaud, Tichkiewitch,S., Zwolinski,P., Editor. 2006, Springer: Dordrecht (The Netherlands).

[EC, 1999] Commission of the European Community. DG XI. "Financial costs of plastics marking". 1999.

[EC, 2010] European Commission, Enterprise and Industry. "Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials". 30 July 2010

[EC 2010b] European Commission. Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines.

[EC 2010c] European Commission. Commission Regulation (EU) No 1015/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household washing machines

[EcoDEEE, 2008] EcoDEEE Consortium, Report of the EcoDEEE project, End of life Recovery conscious design of electr(on)ic equipment, CODDE, November 2008, 91p., http://www.codde.fr/files/Eco_DEEE_Rapport_final_sept09_codde_bv.pdf [in French].

[ecoinvent] Swiss Centre for Life Cycle Inventories. Database ecoinvent data v2.2. (www.ecoinvent.ch/)

[ELCD, 2010] European Commission – Joint Research Centre, European Reference Life Cycle Database (ELCD) core database (Version II), http://lca.jrc.ec.europa.eu/lcainfohub/index.vm (access on May 2012).

[EMPA, 2011] Swiss Federal Laboratories for Materials Science and Technology. Disposal of Flat Panel Display Monitors in Switzerland. (www.swicorecycling.ch/downloads/497/344539/swico_schlussbericht_e_2010.pdf; access June 2012) Final Report. March 2011

[ENSAM, 2002] ENSAM, Integrating the end-of-life aspects during the design of electr(on)ic products. Technical report to ADEME. 2002, ENSAM Chambéry. 111p. (in French).

[van Elburg et al., 2011] M. van Elburg, M. van der Voort, R. van den Boorn, R. Kemna, W. Li. "Study on Amended Working Plan under the Ecodesign Directive (remaining energy-using and new energy-related products)". Prepared for the European Commission under DG ENTR Service Contract: SI2.574204. Draft Report Task 4. 24 August 2011.

[EPTA. 2007] EPTA . 2007. Study for preparing the first Working Plan of the EcoDesign Directive. Report for tender No.: ENTR/06/026. http://ec.europa.eu/enterprise/policies/sustainable-business/files/workingplan_finalreport_en.pdf (Final report: 22/11/2007)

[EU, 2002] "Decision No 1600/2002/Ec of The European Parliament and of The Council of 22 July 2002 laying down the Sixth Community Environment Action Programme".

[EU, 2012] European Parliament legislative resolution of 19 January 2012 on the Council position at first reading with a view to the adoption of a directive of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) (Recast) (http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P7-TA-2012-0009 access February 2012).

[European Council, 2012] Directive 2012/.../EU of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) (Recast). (from: http://register.consilium.europa.eu/pdf/en/12/pe00/pe00002.en12.pdf ; access on July 2012)

[Fraunhofer IZM, 2007] Fraunhofer Institute for Reliability and Microintegration, IZM "EuP Preparatory Studies 'Imaging Equipment' (Lot 4) Final Report". Berlin, 12th November 2007.

[Froelich et al, 2007] Froelich, D., Haoues,N., Leroy,Y., Renard,H., Development of a new methodology to integrate ELV treatment limits into requirements for metal automotive part design. Minerals Engineering, 2007. 20: p. 891-901.

[Gao et al., 2009] J, Li, S, Gao, H. Duan, L. Liu. Recovery of valuable materials from waste liquid crystal display panel. Waste Management 29 (2009) 2033–2039

[Graedel et Allenby, 1996] Graedel, T.E., Allenby,B.R., Design for Environment. 1996: Prentice Hall (USA). ISBN-10 0135316820.

[Graedel et al., 2011] Graedel, T. E., J. Allwood, J.-P. Birat, M. Buchert, C. Hageluken, B. Reck, S. Sibley, and G. Sonnemann. 2011. What do we know about metal recycling rates? Journal of Industrial Ecology. 15: 355–366.

[Grenoble, 2012] The University of Grenoble, Design for Recovery guidelines, ReSICLED (Recovery Strategy Index for End-of-life conscious Design) online software tool (beta version), https://resicled-dev.g-scop.grenoble-inp.fr/ReSICLED-0.1/guidelineDescription/seeGuidelines (accessed on 25/07/2012)

[Griffis and Kwan, 2008] F. H. Griffis, C. M. Kwan. NYSDOT Engineering Design Costs: In-House Versus Outsourced Design. Department of Civil Engineering Polytechnic Institute of NYU. October 30, 2008. (from: http://www.acecny.org/PDF/PolyStudyFinal.pdf ; access July 2012)

[Haoues et al., 2007] Haoues, N., Froelich,D., Brissaud,D., Zwoinski, P. Contribution to integrate constraints of dismantling and recycling in conceptual design. in Proceedings of 1st International seminar on Society & Materials (SAM1). 2007. Seville (Spain).

[Hislop et Hill, 2011] H. Hislop, J. Hill. “Reinventing the wheel. A circular economy for resource security” Published by Green Alliance, October 2011 ISBN 978-1-905869-46-6. (Access to website July 2012 : http://www.green-alliance.org.uk/uploadedFiles/Publications/reports/Reinventing%20the%20wheel_dbl.pdf)

[Holmes, 2010] I. Holmes. REFLATED - Recovery of Flat panel LCD using Advance Technological processes. Conference: Liquid Crystal Display (LCD) Recycling Problem or Opportunity? York, 13th July 2010.

[IEC/TR 62635, 2012] The International Electrotechnical Commission (IEC). Technical Report IEC/TR 62635 Ed.1.0. “End of Life recyclability calculation for electrical and electronic equipment”. June 2012.

[ISIS, 2007] ISIS. Preparatory study for Ecodesign requirements of EuP – Lot 14 Domestic Washing machines and Dishwashers. Final report. December 2007.

[ISO 1043-2, 2011] ISO 1043-2 Plastics—Symbols—Part 2: Fillers and Reinforcing Materials.2011

[ISO 1043-4, 1998] ISO 1043-4 Plastics—Symbols—Part 4: Flame Retardants.1998.

[ISO9773, 1998] ISO 9773.Plastics -- Determination of burning behaviour of thin flexible vertical specimens in contact with a small-flame ignition source. 1998.

[ISO9772, 2001] ISO 9772. Cellular plastics — Determination of horizontal burning characteristics of small specimens subjected to a small flame. 2001

[ISO11469, 2000] ISO 11469. Plastics – Generic identification and marking of plastics products. 2000

[IZM, 2007] Fraunhofer Institute for Reliability and Microintegration, IZM. EuP Preparatory Studies “Televisions” (Lot 5) Final Reports on Tasks 1-8. Berlin. August 2007

[Johansson, 1997] Johansson, G., Design for disassembly - A framework, in Graduate School of Management and Industrial Engineering. Licentiate thesis. 1997, Linköping Universitet: Linköping (Suède). p. 108p.

[JRC, 2006] A. Tukker, G. Huppes, J. Guinée, R. Heijungs, A. de Koning, L. van Oers, S. Suh. T. Geerken, M. Van Holderbeke, B. Jansen, P. Nielsen. “Environmental Impact of Products (EIPRO) Analysis of the life cycle environmental impacts related to the final consumption of the EU-25”. European Commission – Joint Research Centre – Institute for prospective technological studies. May 2006.

[JRC, 2010] International Reference Life Cycle Data System (ILCD) Handbook. Guidance documents on Life Cycle Assessment. European Commission - Join Research Centre - Institute for Environment and Sustainability. Available at: http://lct.jrc.ec.europa.eu/publications.

[JRC, 2011] European commission Joint Research Centre. “Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive”. Final Deliverables (available at: http://lct.jrc.ec.europa.eu/assessment/projects). July 2011.

[Kim et al., 2009] H.-J. Kim, S. Kernbaum, G. Seliger. Emulation-based control of a disassembly system for LCD monitors. Int J Adv Manuf Technol (2009) 40:383–392

[Koyama et al., 2009] Koyama, K., Kitajima,A., Tanaka,M. “Selective leaching of rare earth elements from an Nd-Fe-B-magnet” Kidorui 2009. pp. 36 – 37.

[Lacoste et al., 2011] Lacoste, R., Robiolle, M., Vital, X., Ecodesign in the electronics, Dunod Publisher, ISBN 978-2-10-054892-7, Paris 2011 [in French].

[Lagerstedt et Luttrop, 2006] Lagerstedt, J., Luttrop,C., Guidelines in ecodesign: a case study from railway industry, in Innovation in Life cycle Engineering and Sustainable development, D. Brissaud, Tichkiewitch,S., Zwolinski,P., Editor. 2006, Springer: Dordrecht (The Netherlands).

[Lambert, 2002] A. J.D Lambert. Determining optimum disassembly sequences in electronic equipment. Computers & Industrial Engineering 43 (2002) 553–575

[Lee and Cooper, 2008] S-J Lee , J. Cooper. Estimating Regional Material Flows for LCDs. Proceedings of the IEEE International Symposium on Electronics and the Environment ISEE (May 2008).

[Liang et al., 2007] M-T Liang, WH Tsao, CW Lin, WL Tsao. Studies On The Life-Cycle Cost Analysis Of Existing Prestressed Concrete Bridges. Journal of Marine Science and Technology, Vol. 15, No. 3, pp. 247-254 (2007)

[Luda, 2011] M. L. Luda. In “Integrated Waste Management - Volume II”. Sunil Kumar (ed.). InTech Publisher, August, 2011.

[Mathieux et al., 2001] Mathieux, F., Rebitzer,G., Ferrendier,S., Simon,M., Froelich,D., Ecodesign in the European Electr(on)ics Industry - An analysis of the current practices based on cases studies. Journal of Sustainable Product Design, 2001. 1(4): p. 233-245.

[Mathieux, 2002] Mathieux, F., Towards better integration of the end-of-life recovery aspects at the design stage of a product - A method based on the multicriteria assessment of the product's recyclability and on the identification of weak points of its design., in Institute Design, Mechanical Engineering and Environment. PhD thesis. 2002, ENSAM: Chambéry (France). p. 288p. (in French).

[Mathieux et al., 2008] Mathieux, F., Froelich,D., Moszkowicz,P., ReSICLED: a new Recovery-Conscious Design method for complex products based on a multicriteria assessment of the recoverability. Journal of Cleaner Production, 2008. 16(3): p. 277-298.

[McDonnell et Williams, 2010] T J McDonnell, K S Williams. The location and character of mercury in waste LCD backlights. Summary research report. September 2010.

[Meskers et al., 2009] C.E.M. Meskers, C. Hagelüken, S. Salhofer, M. Spitzbart - EMC 2009. Impact of pre-processing routes on precious metal recovery from PCs. European metallurgical conference, 2009. 28 June – 1 July. Insbruck. Austria. (http://www.preciousmetals.umicore.com/PMR/Media/e-scrap/show_impactOnPreprocessingRoutes.pdf)

[Mineta et Okabe, 2005] K. Mineta, T. H. Okabe. Development of a recycling process for tantalum from capacitor scraps. Journal of Physics and Chemistry of Solids 66 (2005) 318–321

[Mohite, 2005] S.B.E. Mohite. “Disassembly Analysis, Material Composition Analysis and Environmental Impact Assessment of Computer Disk Drives”. Texas Tech University, Thesis In Industrial Engineering, 2005.

[Noguchi et al., 1998] T. Noguchi, H. Tomita, K. Satake, H. Watanabe. A New Recycling System for Expanded Polystyrene using a Natural Solvent. Part 3. Life Cycle Assessment. Packaging Technology and Science. 11, 39-44 (1998).

[Oakdene Hollins , 2011] Oakdene Hollins Ltd. “Study into the feasibility of protecting and recovering critical raw materials through infrastructure development in the south east of England. Final report”. European Pathway to Zero Waste. Project Ref: LIFE08 ENV/UK/000208. March 2011.

[Okabe et al., 2003] T. H. Okabe, O. Takeda, K. Fukuda, Y. Umetsu. Direct Extraction and Recovery of Neodymium Metal from Magnet Scrap. Materials Transactions, Vol. 44, No. 4 (2003) pp. 798 – 801.

[PE, 2011] PE Europe GMBH. Professional database. Software GaBi, ver. 4.4. www.gabi-software.com/

[PlasticsEurope] PlasticsEurope – (former Association for Plastics Manufacturing in Europe - APME). "Ecoprofiles of the European Plastics Industry".

[Plouffe et al., 2011] S. Plouffe, P. Lanoie, C. Berneman, M-F Vernier. Economic benefits tied to ecodesign. Journal of Cleaner Production 19 (2011) 573-579

[Rabah, 2008] M. A. Rabah. Recyclables recovery of europium and yttrium metals and some salts from spent fluorescent lamps. Waste Management 28 (2008) 318–325

[Renault, 1994] Renault, Design for Recycling guidelines, Ref 00 - 10 - 060, 1994. (in French).

[Renault, 2001] Renault. Recycling indicators. Ref 00 - 10 - 098. 2001 (in French).

[te Riele et al., 2001] H. te Riele, M. van Elburg, R. Kemna. Dematerialisation - Less clear than it seems. Thematic exploration written for the Dutch Ministry of VROM (Environment), January 2001 (http://web.ntpu.edu.tw/~yml/yml/download/ie08s/dematerialisation.pdf, access June 2012)

[Rose, 2000] Rose, C.M., Design for environment: a method for formulating product end-of-life strategies, in Department of Mechanical Engineering. PhD thesis. 2000, Stanford University: Stanford. p. 175p.

[Ross and Evans, 2002] S. Ross, D. Evans. Excluding Site-Specific Data from the LCA Inventory: How This Affects Life Cycle Impact Assessment. Int J LCA 7 (3) 141 - 150 (2002).

[Rüdenauer et Gensch, 2005] I. Rüdenauer, C.O. Gensch. "Eco-Efficiency Analysis of Washing machines. Refinement of Task 4: Further use versus substitution of washing machines in stock". European Committee of Domestic Equipment Manufacturers (CECED). Freiburg, March 18th, 2005.

[Salomone, 1995] Salomone,T.A., What every engineer should know about Concurrent engineering, Ed. Marcel Dekker, 1995, ISBN 0-8247-9578-4 »

[Salhofer et al., 2011] S. Salhofer, M. Spitzbart, K. Maurer. Recycling of LCD screens in Europe – State of Art and Challenges. in Glocalized Solutions for Sustainability in Manufacturing. 2011, 454-458, DOI: 10.1007/978-3-642-19692-8_78.

[Schüler et al., 2011] D. Schüler, M. Buchert, R. Liu, S. Dittrich, C. Merz. Study on Rare Earths and Their Recycling. Final Report for The Greens/EFA Group in the European Parliament. January 2011.

[Spatari et al., 2003] S Spatari, M Bertram, K Fuse, T.E Graedel, Eric Shelov. The contemporary European zinc cycle: 1-year stocks and flows. Resources, Conservation and Recycling. Volume 39, Issue 2, September 2003, Pages 137-160.

[Stena, 2010] Stena Metall Group. http://corporate.stenametall.com/News-and-media/News-archive/Stena-launches-a-unique-process-for-recycling-LCD-screens/ (access September 2012)

[Takeda et al., 2009] Takeda,O., Nakano,K., Sato,Y. "Resource recovery from waste of rare earth magnet by utilizing fluoride molten salts" Yooyuen oyobi Koon Kagaku 2009 (pp. 63 – 70).

[Tange et Drohmann, 2005] L. Tange, D. Drohmann. Waste electrical and electronic equipment plastics with brominated flame retardants e from legislation to separate treatment e thermal processes. Polymer Degradation and Stability 88 (2005) 35-40.

[Tange et Slijkhuis, 2009] Tange, L. and C. Slijkhuis. 2009. The classification of WEEE plastic scrap in view of PBB's & PBDE's. An overview of WEEE categories within the current recycling practice., European Electronics Recyclers Association (EERA) & European Brominated Flame Retardant Industry Panel (EBFRIP), Brussels.

[Torres et al., 2009] F. Torres, S. Puente , C. Dıaz. Automatic cooperative disassembly robotic system: Task planner to distribute tasks among robots. Control Engineering Practice 17 (2009) 112– 121

[TU Wien, 2008] TU Wien, EcoDesign Pilot webpage. 2008: http://www.ecodesign.at/pilot/ONLINE/ENGLISH/, Accessed on 6/03/2008.

[UN, 2011] United Nations Commodity Trade Statistics Database (http://comtrade.un.org/). Access on October 2011.

[UNEP, 2001] UNEP, Consumption opportunities - Strategies for change - A report for decision-makers, Geneva, 2001

[UNEP, 2010] UNEP. Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management. Hertwich, E., van der Voet, E., Suh, S., Tukker, A, Huijbregts M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y.

[UNEP, 2010b] Metal Stocks in Society - Scientific Synthesis, A Report of the Working Group on Global Metal Flows to the International Panel for Sustainable Resource Management. Graedel, T.E., Dubreuil, A., Gerst, M., Hashimoto, S., Moriguchi, Y., Müller, D., Pena, C., Rauch, J., Sinkala, T., Sonnemann, G.. UNEP.

[UNEP, 2011] UNEP. Recycling Rates of Metals. A Report of the Working Group on Global Metal Flows to the International Panel for Sustainable Resource Management. Graedel, T.E., Allwood, J.; Birat, J-P.; Reck, B.K.; Sibley, S.F.; Sonnemann, G.; Buchert, M.;Hageluken, C. 2011

[UNEP, 2011b] UNEP. “Metal Recycling. Opportunities, Limits, Infrastructure”. 11th November 2011. (draft zero). Study under development.

[UNEP 2011c] UNEP 2011. Draft Glossary of Terms Used by the International Resource Panel. Version 0.1 24.08.2011. (www.unep.org/resourcepanel/Portals/24102/PDFs/IRP_Draft_Glossary.pdf)

[USGS, 2011] United States Geological Survey website (www.usgs.gov). Access on October 2011.

[van der Voet et al., 2005] Ester van der Voet, Lauran van Oers, Stephan Moll, Helmut Schütz, Stefan Bringezu, Sander de Bruyn, Maartje Sevenster, Geert Warringa. “Policy Review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries”. Commissioned by European Commission, DG Environment, to support the Thematic Strategy for the Sustainable Use of Natural Resources. 2005.

[van Oers et al., 2002] van Oers, L., De Koning, A., Guinée, J.B., Huppes G. 2002. Abiotic resource depletion in LCA; Improving characterization factors abiotic resource depletion as recommended in the new Dutch LCA handbook. RWS-DWW report.

[VHK, 2011] van Holsteijn en Kemna B.V. (VHK). “Final Report. Methodology for Ecodesign of Energy-related Products MEErP 2011.Methodology Report Part 2: Environmental policies & data. (28 November 2011)”, and “Eco-Design of Energy Related/Using Products. Ecoreport 2011. Version 2.” (http://www.meerp.eu/documents.htm; access April 2012)

[Williams, 2004] E. Williams. Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input-Output Methods. Environmental Science & Technology. 2004, 38, 6166-6174.

[WRAP, 2010] Waste and Resource Action Programme (WRAP). Demonstration of recycled content in electrical products. (www.wrap.org.uk/downloads/Demonstration_of_recycled_content_in_electrical_products_summary_report.f7ef0ac9.8913.pdf access December 2011).

[Zwolinski et al., 2006] Zwolinski, P., Lopez Ontiveros, M.A., Brissaud, D., Integrated design of remanufacturable products based on product profiles. Journal of Cleaner Production, 2006. 14(15-16): p. pp 1333-1345.

Annex 1 – Materials flow in the EU

Table A1.1. Consumption of materials, end uses and recycling rates

Material	**Mass used in EU** (internal production + imports - exports)		**End-use products** (from [2] unless differently specified)			**Average recycling rates**
	[10^6 kg]	References	Products	Share [%]	Notes	
Aluminium	**5,020.34**	[1]; from HS 7601 to HS 7616 [3]	Transport	30.0%	EAA, 2009 [9]	35% [2]; 40-50% [5]
			Building	29.0%		
			Packaging (16%)	20.0%		
			Engineering	14.0%		
			Other (goods, paint, pyrotechnics)	7.0%		
Antimony (*)	**16.84**	[1]; HS 8110, HS 261710 and HS 282580 [3]	flame retardant	72.0%		11% [2]
			Batteries	19.0%		
			Glasses	9.0%		
			Semiconductors	0.01%		
Barite	**390.58**	[1]; HS 2511 [3]	Drilling mud	84.0%		0% [2; 4]
			Electronics	3.0%		
			Ceramic glazes	3.0%		
			Medical application	1.0%		
			Sound deadening	6.0%		
			Rubber/glass	3.0%		
Bauxite	**12,488.43**	Estimation for 2008 from [2]; HS 2606 [3]	Aluminium	85.9%		0% [2; 4]
			Non metallurgical alumina	10.0%		
			Portland cement	0.7%		
			Calcium aluminate cement	0.3%		
			Steel	0.3%		
			Refractories	0.9%		
			Abrasives	0.7%		
			Mineral fibres	0.7%		
			oil and gas drilling	0.3%		
			Chemicals	0.2%		
Bentonite	**2,484.89**	[1]; HS 250810 [3]	foundry sand	33.0%		0% [2]
			Iron ore pelletizing	21.0%		
			Cat litter	19.0%		
			civil engineering	8.0%		
			Drilling mud	6.0%		
			Detergent	6.0%		
			Vegetal oil refining	5.0%		
			Paper	2.0%		
Beryllium (*)	**0.01**	[4]; HS 811212, HS 811213, HS 811219 [3]	Electronics	20.0%		19% [2]; 14% - 75% [5]
			households	20.0%		
			Road transport	10.0%		
			aircraft	5.0%		
			Consumer's goods	15.0%		
			Rubber, plastics and glass	10.0%		
			Metals	5.0%		
			Mechanical equipment	15.0%		
Borates	**230.55**	[1]; HS 2528, HS 2840 [3]	Glass	37%		0% [2; 4]
			Frits & ceramics	19%		
			Cleaning	26%		

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
			Chemicals	3%		
			Agriculture	2%		
			Flame retardants	3%		
			Industrial fluids	3%		
			Metallurgy	1%		
			Wood preservation	1%		
			Other	5%		
Cadmium	**0.07**	[1]; HS 8107, HS 850730 (partially) [3]	Batteries	81.0%	(end-use from [6])	76% [5]
			Pigments	11.0%		
			Coatings	6.0%		
			Stabilisers	1.5%		
			Minor uses	0.5%		
Chromium	**393.93**	[1]; HS 2610, HS 2819, HS 811221, HS 811222 and HS 811229 [3]	Steel	95.0%		13% [2]; 44% for USA [4]; 60-72% [5]
			Pigment	2.0%		
			Refractories	3.0%		
Clays	**11,278.76**	[2]; HS 2507 and HS 2508 [3]	ceramics	61.0%		0% [2; 4]
			fibreglass	5.0%		
			paper	16.0%		
			others (paints, rubber, plastics, refractories)	18.0%		
Cobalt (*)	**52.45**	[1] ; HS 2605, HS 2822 and HS 8105 [3]	Batteries	49.0%		68% [5]
			Superalloys and magnets	16.0%		
			Hard metal and surface treatment	12.0%		
			Pigment	9.0%		
			Catalyst	6.0%		
			Other (pigment, paints, adhesives, etc.)	8.0%		
Copper	**3,525.91**	[1]; HS 2603, from HS 7401 to HS 7413, and estimation of copper into vehicles and EEE [3]	Construction (wires, pipes, switches, lock, etc.)	23.0%		20-40% [2]; 24-78% [5]
			equipment manufacturing	12.0%		
			road transport	10.0%		
			Other transport	4.0%		
			Electronics	13.0%		
			Electrical equipment	28.0%		
			Others (lighting, clocks, households, decoration, etc.)	10.0%		
Diatomite	**336.44**	[1]; HS 2512 and HS 6901 [3]	filters	48.0%		0% [2; 4]
			Absorbents	9.0%		
			Fillers	8.0%		
			Cement additives	33.0%		
			Insulation	2.0%		
Feldspar	**9,955.30**	[1]; HS 252910 [3]	Glass	60.0%		0% [2; 4]
			Ceramic	35.0%		
			Others (porcelain, glass wool, welding electrodes)	5.0%		
Fluorspar (*)	**612.29**	[1]; [HS 252921 and HS 252922]	Chemicals (Hydrofluoric acid)	60.0%		<1% [2]

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
		[3]	Steel	20.0%		
			Aluminium	12.0%		
			Glass and glass fibres	2.0%		
			Cement	4.0%		
			Other	2.0%		
Gallium (*)	**0.01**	Estimation from [2]	Integrated circuits	63.0%		0% [2]; <1% [5]
			Las diodes and LED	17.0%		
			Special alloys	5.0%		
			Photovoltaic cells	15.0%		
Germanium	**31.10**	[4]; imports for 2007 from [2]	Fibre optic	30.0%		30% for USA [4]; 40% [5]; 0% [2]
			Infrared optics	25.0%		
			Catalysts	25.0%		
			Solar equipment	15.0%		
			Others (metallurgy, medicine)	5.0%		
Gold	**0.13**	[1]; HS 7108 and HS 2843302 [3]	Jewellery and arts	69.0%	end-uses from [4]	15-20% [5]
			electrical and electronics	9.0%		
			dental and other	22.0%		
Graphite (*)	**57.92**	[1]; HS 2504 and HS 3801 [3]	foundries	24.0%		0% [2]
			Steel industries	24.0%		
			Crucible productions	15.0%		
			Electrical application	12.0%		
			Refractories	8.0%		
			Lubricants	5.0%		
			Pencils	4.0%		
			Batteries	4.0%		
			Others	4.0%		
Gypsum	**21,540.47**	[1]; HS 252010 [3]	Wallboard and plaster	82.0%		1% [2]
			Cement	14.0%		
			Agriculture	3.0%		
			Modelling	1.0%		
Indium (*)	**0.09**	data of 2006 and 2008 from [2]	Flat display panels	74.0%		0.3% [2]; 1% [5]
			Architectural glass and windscreens.	10.0%		
			Low melting point alloys:	10.0%		
			Minor alloys (chatodic protection, nuclear applications)	1.0%		
			surface coating	1.0%		
			Semiconductors, LED	2.0%		
			Other use	1.0%		
Iron	**79,926.82**	[1]; from HS 7201 to HS 7229, from HS 7301 to HS 7326, and HS 2601 [3]	Construction (wires, pipes, switches, lock, etc.)	26.0%		52%-66% [5]; 22% [2]; 58% [4]
			automotive	16.0%		
			Mechanical engineering	14.0%		
			tubes	12.0%		
			Metal goods	12.0%		
			Structural	11.0%		
			domestic appliances	4.0%		
			Shipyard	1.0%		
			Others	4.0%		
Lead	**135.60**	[1]; HS 2607, HS	Batteries	80.0%		50% [1]; 95-

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
		2824, HS 7801, HS 7802, HS 7804, and HS 7806 [3]	Cable sheathings	1.0%		96% [5]
			rolled/extruded products	6.0%		
			Ammunitions	3.0%		
			Alloys	2.0%		
			Paint and glass pigments	5.0%		
			Others	3.0%		
Limestone	**28,074.46**	[1]; HS 2521 [3]	Iron and steel	21.0%		0% [2]
			Non ferrous	2.0%		
			building materials	19.0%		
			environmental treatment plant (flue gas, wastewater, drinking waters)	9.0%		
			chemicals	5.0%		
			Papers	22.0%		
			Plastics	5.0%		
			Paints and coatings	8.0%		
			Agriculture	8.0%		
			Other	1.0%		
Lithium	**111.47**	[1]; HS 282520, HS 283691, HS 850650 [3]	Batteries	20.0%		0% [2]; <1% [5]
			Glass and ceramics	37.0%		
			Lubricants grease	11.0%		
			Gas and air treatment	5.0%		
			Aluminium smelting	7.0%		
			rubber and plastics	3.0%		
			Pharmaceutical	2.0%		
			Aluminium alloys	0.4%		
			Construction	2.0%		
			continuous casting	5.0%		
			electronics	0.2%		
			Others	7.4%		
Magnesium (*) and magnesite	**1,889.96**	[1]; HS 2519; HS 253020; HS 2816; HS 282731; HS 283321; HS 8104 [3]	Casting alloy (for car's components)	50.0%		33% [2]; 42% [5]
			Wrought alloy	2.0%		
			Aluminium alloy (packaging)	17.0%		
			Aluminium alloy (transport)	9.0%		
			Aluminium alloy (construction)	5.0%		
			Aluminium alloy (others)	3.0%		
			Others	14.0%		
Manganese	**572.71**	[1]; HS 2602, HS 2820, HS 8111 and HS 850610 [3]	Iron and steel	90.0%		18.5% [2]; 33-67% [5]
			Non steel alloys	6.0%		
			Batteries	2.0%		
			Other	2.0%		
Mercury	**0.63**	[1]; HS 280540, HS 2852, HS 853932 (for 2008) [3]	chlor-alkali plants	41.2%		25% [7]; 97% [5]
			Lamps	3.1%		
			Batteries	3.8%		
			Dental amalgams	23.5%		
			Measurement equipment	2.8%		
			switches	0.1%		
			chemical	10.2%		

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
			Others	15.3%		
Molybdenum	**63.30**	[1]; HS 2613 [3]	Stainless steel	29.0%		17% [2]; 33%-67% [5]
			Full alloy steel	17.0%		
			Tool and high speed steels	10.0%		
			HSLA steel	8.0%		
			Carbon steel	9.0%		
			Catalysts (mainly petroleum refining)	8.0%		
			Mo Metal and Mo-based-alloys	7.0%		
			Superalloys	5.0%		
			Cast iron	3.0%		
			Lubricants	2.0%		
			Other	2.0%		
Nickel	**19.66**	[1]; HS 2604, HS 7501, HS 7502, HS 7503, HS 7504, HS 7505, HS 7506, HS 7507, and HS 7508 [3]	Stainless steel	70.0%		32% [2]; 66%-70%[5]
			Ni-alloys	11.0%		
			Plating	5.0%		
			Full alloy steel, bearing steel, tool steel	5.0%		
			Batteries	3.0%		
			Catalysts	1.0%		
			Other	5.0%		
Niobium	**19.70**	data of 2006 from [2]	Ferro-niobium	68.0%		11% [2]; 44-56% [5]
			Ferro-niobium (construction)	22.0%		
			Alloys	10.0%		
Perlite	**1,090.33**	[1]; HS 253010 [3]	Construction	60.0%		0% [2]
			Horticulture	109033.2%		
			fillers	109033.2%		
			filter aid	7.0%		
			Other	7.0%		
Phosphate	**4,515.48**	[1]; HS 2510, and HS 2835 [3]	Fertilizes	90.0%		0% [4]
			Others (detergent, animal feedstock)	10.0%		
Platinum (PGM) (*)	**0.72**	Estimation of 2007 from [2]; HS 7110; HS 7111, HS 711292, HS 711510, HS 711021, HS 711029, HS 711031, and HS 711039 (values 2008) [3]	Auto catalyst	53.0%		35% [2]; 60%-70% [5]
			Jewellery	20.0%		
			Electric and electronics (capacitors, thermocouples, hard drives)	11.0%		
			Dental alloys	6.0%		
			Catalysts: Chemicals	6.0%		
			Glass making equipment (esp. LCD	2.0%		
			Catalysts: Petroleum	1.0%		
			Other	1.0%		
Potash	**2,363.31**	[1]; HS 2815 [3]	Fertilizers	85.0%		0% [4]
			chemicals	15.0%		
Rare Earth (*)	**17.6**	No detailed figures available for all the different elements.	Catalysts	20.0%		1% [2]
			Glass	12.0%		
			Polishing	12.0%		
			Metallurgy: iron and steel	6.0%		

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
		Overall data from [2] estimated for the 2006.	Metallurgy: Al and Mg alloys	1.0%		
			Metallurgy: batteries	8.0%		
			Magnets	19.0%		
			Phosphors	7.0%		
			Pigments	1.0%		
			Ceramics: capacitors	1.0%		
			Ceramics: other	4.0%		
			Other	9.0%		
Rhenium	**0.04**	[4]; data from 2006 [2]	Catalysts	20.0%		13% [2]; 50% [5]
			Superalloys	70.0%		
			Others	10.0%		
Salt	**51,432.63**	[1]; HS 2501 [3]	chemical industry	40.0%	end-uses from [4]	0% [4]
			Road de-icing	38.0%		
			distributors	8.0%		
			food	4.0%		
			agricultural	4.0%		
			general industrial	2.0%		
			water treatment	2.0%		
			others	2.0%		
Silica-sand	**58,010.62**	data of 2006 from [2]; HS 250510 [3]	Glass (flat & container glass)	38.0%		24% [2]
			Foundry	17.0%		
			Building materials	30.0%		
			Others (fibreglass, chemicals, abrasives, leisure, filtration)	15.0%		
Selenium	**1.22**	[1]; HS 280490 [3]	electronics	35.0%		no data (low percentages)
			glass manufacturing	30.0%		
			chemicals and pigments	20.0%		
			other (including agriculture and metallurgy)	15.0%		
Silicon	**909.78**	[1]; HS 720221, HS 720229, HS 280461, HS 280469, and HS 281122 [3]	construction (conservation and protection, sealants)	41.0%	end-use from : CES (Centre Européen des Silicones)	0% [4]
			electronics (PV, chips)	8.0%		
			Industrial (industrial equipment and moulds, plastics, chemicals)	21.0%		
			Personal and lifestyle (health and medical care, personal and home care)	15.0%		
			Transportation	2.0%		
			Others (adhesive and coatings, paper, textile and leather)	13.0%		
Silver	**12.05**	[1]; HS 261610, HS 7106 and HS 711311 [3]	Jewellery and silverware	34.0%		30% - 50 % [5]
			Photography	18.0%		
			Electrical/Electronics (contacts)	23.0%		
			Dental	5.0%		
			Catalysts	6.0%		

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
			Mirrors and reflective glass	2.0%		
			Solar panels	4.0%		
			Batteries	2.0%		
			Plasma displays	1.0%		
			Water treatment	3.0%		
			RFID-tags	1.0%		
			Coins	1.0%		
Sulphur	**5,230.09**	[1]; HS 2503, HS 2802 [3]	Agricultural chemicals (fertilizers)	60.0%		20-40% (reclaimed from petroleum refining) [4]
			petroleum refining	24.0%		
			metal mining	4.0%		
			Other uses	12.0%		
Talc	**1,306.26**	[1];HS 2526 [3]	Paper	40.0%		0% [2]
			Plastics	18.0%		
			Ceramic & refractories	13.0%		
			Paints & coatings	12.0%		
			Others (feed materials, personal care, rubber, roofing)	17.0%		
Tantalum (*)	**0.45**	[1]; Data from 2006 [2]; HS 8103 [3]	Capacitors	60.0%		4.5% [2]
			Cemented carbides (tools)	16.0%		
			Aerospace & automobile	14.0%		
			Process equipment	4.0%		
			Surgical applications and other	6.0%		
Tellurium	**0.76**	[4]; Data from 2006 [2]	Metallurgy	42.0%		0% [2; 5]
			Photovoltaic cells	26.0%		
			Chemicals and pharmaceuticals	21.0%		
			Electronics and other	11.0%		
Tin	**18.17**	[1]; HS 2609, HS 8001, HS 8002, HS 8003 [3]	electrical	28.0%	end-uses from [4]	50% [5];
			cans and containers	19.0%		
			construction	13.0%		
			transportation	12.0%		
			other	28.0%		
Titanium	**831.72**	[1]; HS 2614, HS 2823, HS 8108,and HS 320611 [3]	paints	56.0%		6% [2]; 11% [5]
			plastics	23.0%		
			paper	11.0%		
			other (catalyst, ceramics, ink)	5.0%		
			plant construction	2.0%		
			aerospace	2.0%		
			other (medicine, sports-goods, jewellery)	1.0%		
Tungsten (*)	**7.65**	[1]; HS 2611, HS 8101, and HS 853921 [3]	Cemented carbides	60.0%		37% [2]; 80% [5]
			Alloy steels (tool steel)	13.0%		
			Superalloys	6.0%		
			Fabricated products	17.0%		
			Tungsten alloys	4.0%		
Vanadium	**0.12**	[1]; Data from 2006 [2]	Steel: HSLA	35.0%		0% [2; 4]
			Steel: Full alloy	25.0%		
			Steel: Tool/stainless	18.0%		
			Steel: Carbon	12.0%		

Material	Mass used in EU (internal production + imports - exports)		End-use products (from [2] unless differently specified)			Average recycling rates
	[10^6 kg]	References	Products	Share [%]	Notes	
			Chemical applications	5.0%		
			Non-ferrous alloys: mostly Ti-alloys	4.0%		
			Other	1.0%		
Zinc	**1,678.35**	[1]; HS 2608, HS 2817, HS 7901, estimation of zinc into galvanized steel, vehicles and EEE [3]	Galvanization	46.0%		15% [8]; 41% [4]; 19% -71% [5]
			Brass & bronze	18.0%		
			Zinc-based alloys (for casting)	14.0%		
			Chemicals (rubber, pharmaceuticals)	10.0%		
			Zinc semi-manufactures (rolled zinc, wire, pipes)	10.0%		
			Other	2.0%		
(*) Note: EU Critical Raw Materials						
[1] British Geological Survey - European Mineral Statistics '2005-2009' - (data for 2009)						
[2] European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials						
[3] United Nations Commodity Trade Statistics Database (http://comtrade.un.org/)						
[4] United States Geological Survey website (www.usgs.gov)						
[5] UNEP - Recycling Rates of Metals, A status report (world average)						
[6] International Cadmium Association - report of Hugh Morrow "Cadmium"						
[7]COWI - Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society						
[8] International Zinc Association - www.zinc.org						
[9] EAA: http://www.alueurope.eu/pdf/EAA_activity_report_2010_V10_2.pdf						

Table A1.2. Consumption of polymers, end uses and recycling rates

Polymers	**Volumes Sold** (EU-27 2010 [1]) [10^6 kg]	Prodcom n°	**End-uses**	**Recycling rate**
ABS	752	20162070	Automotive (e.g. bumper), enclosures for electrical and electronic assemblies, components of furniture, protective cases, kitchen appliances, toys.	No data available
EPS	2164	20162035	Building & Construction, and packaging	28% [2
PE-HD	5998	20161050	Mainly packaging, followed by building components, electrical and electronic equipment, automotive, and others	31 % (average value for European PE in 2009) [3]
PE-LD and PE-LLD	5907	20161035 and 20161039	Mainly packaging, followed by building components, electrical and electronic equipment, automotive, and others	31 % (average value for European PE in 2009) [3]
PA	2543	20165450 and 20165490	Textile (nylon), production of aramid fibres for reinforced components (protections, sport equipment, cables, construction, etc.)	No data available (few recycling processes of PA are published, mainly related to production of textile and carpets)
PC	953	20164040	electronics, CD/DVD, constructions (glazing), transport, others	Few data available (estimation <1% [6])
PET	2879	20164062 and 20164064	Mainly packaging. Few quantities in other applications (textile, carpet, automotive, upholstery, furniture, etc)	28% (data for USA 2009) [4]
PP	8727	20165130	Injection moulding 36% ; fibres 23%; film and sheets 14%; blow moulding 1%; ropes 3%; Others 23%	Recycling rate 14.9% [3]; End-use detail for America in 2004 [5]
PS	1852	20162039	Mainly packaging, building materials, electrical and electronic products, and others	Very low percentages (Estimation <1% from [6])
PUR	3000	20165670	Building & Construction 26.8%; Transportation 23.8%; Furniture & Bedding 20.7%; Appliances 5.1%; Packaging 4.6%; Textiles, Fibres & Apparel 3.3%; Machinery & Foundry 3.3%; Electronics 1.4%; Footwear 0.7%; Other 10.2%	30.6% (USA data for 2008 from [7]); end-uses detail from [7]

[1] Eurostat - Statistics on the production of manufactured goods - Sold Volume - 2010 (from Eurostat website)
[2] www.foam-control.com/downloads/brochure/2010%20EPS%20Recycling%20Rate%20Report%208_5x11.pdf
[3] PlasticsEurope - The recycling and recovery of Polyolefins waste in Europe
[4] www.napcor.com/pdf/2009_Report.pdf
[5] www.albertacanada.com/documents/Alberta_PP_Report.pdf
[6] www.plasticfreebottles.com/pdf/Understanding-Plastic-Codes.pdf
[7] www.polyurethane.org

Annex 2 – Specific impacts of materials

Table A2.1. Specific environmental impacts of materials (per kg)

Material	Impact category	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication fresh water	Aquatic eutrophication marine water	Human toxicirty	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Water consumption	Agricultural land occupation	Urban land occupation	Note and references
	Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil	Freshwater	ALOP	ULOP	
[1 kg]	Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ	kg	m2*yr	m2*yr	
Aluminium		9.9E+00	4.8E-02	1.7E-02	1.0E-06	1.0E-02	8.6E-06	5.5E-03	2.7E-01	4.1E-02	3.2E-02	4.2E-06	8.8E+01	5.7E+01	n.a	n.a	PrimaryAluminium ingot - EEA (2005)
Baryte		2.0E-01	9.5E-04	4.6E-04	1.0E-08	2.9E-04	2.0E-06	1.5E-04	6.7E-03	1.7E-02	1.4E-03	4.1E-05	2.6E+00	1.5E+02	5.4E-03	1.4E-03	Barium sulphate (Ecoinvent - Estimation)
Bauxite		7.9E-03	9.5E-05	1.3E-04	8.5E-10	1.6E-03	4.7E-08	5.0E-05	1.4E-04	3.0E-04	2.4E-05	1.0E-08	1.0E-01	6.7E-01	5.7E-05	3.6E-04	Bauxite (at the Mine) Ecoinvent - 2002
Bentonite		5.2E-01	4.5E-03	1.5E-03	1.7E-07	1.2E-03	7.8E-05	4.6E-04	4.7E-02	4.2E-02	6.2E-03	5.5E-06	1.0E+01		1.7E-02	1.0E-02	Bentonite (Ecoinvent - 2000)
Borates		8.2E-02	6.0E-04	7.9E-04	8.7E-09	1.7E-03	4.6E-07	3.0E-04	1.4E-03	3.0E-03	2.6E-04	6.7E-04	1.1E+00	1.0E+00	3.8E-04	7.3E-03	Sodium Borates (Ecoinvent - 2000)
Cadmium		8.7E-01	4.7E-03	2.1E-03	4.7E-08	1.5E-03	1.3E-05	6.8E-04	3.2E-02	1.2E-01	1.4E-02	4.1E+00	1.1E+01	3.2E+01	3.3E-02	8.0E-03	Primary Cadmium (Ecoinvent - 2005)
Chromium		2.7E+01	1.0E-01	5.1E-02	2.1E-06	4.4E-02	4.6E-04	1.6E-02	1.2E+00	5.1E+00	2.6E+00	6.5E-04	3.3E+02	6.3E+02	2.6E-01	1.6E-01	Chromium (Ecoinvent - 2000)
Clays		2.9E-03	2.2E-05	3.5E-05	3.6E-10	1.2E-05	1.5E-08	1.3E-05	3.6E-05	6.4E-05	5.7E-06	3.6E-09	4.0E-02	1.1E-02	3.9E-06	1.7E-04	Clay mining (Ecoinvent - 2002)
Cobalt (*)		9.0E+00	8.1E-02	8.7E-02	6.3E-07	5.1E-02	1.3E-04	3.9E-02	7.4E-01	7.8E-01	5.9E-02	4.9E-05	1.0E+02	4.9E+02	3.8E-01	9.2E-01	Cobalt (Ecoinvent - 2000)
Copper		3.6E+00	5.5E-01	8.8E-02	2.6E-07	1.5E-01	9.1E-05	2.4E-02	2.2E+00	6.0E+00	2.1E+00	2.0E-03	4.4E+01	2.0E+02	2.3E-01	2.4E+00	Primary copper (Ecoinvent - 2003)
Feldspar		3.4E-02	9.8E-05	1.2E-04	4.7E-09	4.3E-05	1.6E-07	4.4E-05	3.7E-04	1.4E-03	1.5E-04	8.0E-08	4.7E-01	1.9E+00	1.9E-04	3.8E-03	Feldpsar (Ecoinvent - 1995)
Fluorspar (*)		1.7E-01	1.1E-03	4.0E-04	1.3E-08	5.4E-04	4.8E-06	1.2E-04	2.5E-02	4.3E-02	6.1E-03	4.1E-06	2.2E+00	3.5E+00	1.3E-02	2.9E-03	Calcium Fluoride (Ecoinvent - 1991)
Gallium (*)		1.9E+02	5.0E-01	3.0E-01	1.8E-05	1.6E-01	1.3E-02	3.4E-01	7.4E+00	2.3E+01	1.4E+00	9.2E-04	2.2E+03	6.9E+03	2.1E+00	8.0E-01	Gallium (semicondutor grade) (Ecoinvent - 2005)
Gold		1.9E+04	1.7E+02	1.7E+02	1.8E-03	6.6E+01	1.6E-01	6.5E+01	2.6E+03	5.8E+03	8.7E+02	5.8E+01	2.4E+05	6.8E+05	3.4E+02	6.1E+03	Gold primary (Ecoinvent - 2004)
Graphite (*)		2.9E-02	1.4E-04	9.3E-05	2.2E-09	1.0E-04	1.7E-07	3.3E-05	7.5E-04	1.7E-03	1.5E-04	7.3E-08	3.7E-01	7.6E-01	2.7E-04	1.8E-04	Graphite (Ecoinvent - estimation 2000)
Gypsum		1.1E-01	1.3E-04	1.1E-04	3.7E-09	3.7E-05	2.2E-07	3.8E-05	2.2E-03	8.9E-05	5.5E-05	1.9E-05	1.3E+00	1.4E-01	n.a	n.a	Gypsum plaster (CaSO4 beta semihydrates) (ELCD - 2002)
Indium (*)		1.6E+02	2.0E+00	8.4E-01	8.1E-06	5.4E-01	9.5E-04	3.1E-01	8.1E+00	1.1E+01	8.3E+00	1.3E-01	2.0E+03	6.0E+03	3.0E+00	4.2E+00	Primary indium (Ecoinvent - 2005)
Iron		3.2E+00	9.8E-03	6.0E-03	2.5E-07	2.2E-03	4.8E-05	1.8E-03	1.3E-01	8.5E-02	1.2E-03	7.2E-08	3.6E+00	n.a	n.a	n.a	Steel sheet primary (BUWAL - 1996)
Lead		1.8E+00	4.1E-02	8.1E-03	1.2E-07	7.2E-03	1.1E-06	1.1E-03	3.0E-02	9.5E-03	5.8E-03	2.1E-03	2.0E+01	8.8E+00	n.a	n.a	Lead primary (ELCD - 2002)
Limestone		9.3E-01	2.9E-04	2.9E-04	3.0E-09	8.9E-05	4.4E-07	1.0E-04	4.3E-03	2.5E-04	2.4E-03	1.1E-08	3.6E+00	8.2E-01	n.a	n.a	Limestone hydrate (Ca(OH)2) (PE -2000)
Lithium		1.9E+01	9.7E-02	3.8E-02	1.7E-06	2.8E-02	1.5E-04	1.3E-02	8.3E-01	1.4E+00	1.4E-01	5.2E-05	2.4E+02	8.5E+02	3.1E-01	8.1E-02	Lithium (Ecoinvent - 2006)
Magnesium (*)		7.8E+01	2.4E-02	1.9E-02	6.9E-07	8.2E-03	3.1E-04	9.4E-03	2.1E-01	2.7E-01	5.3E-02	5.5E-06	9.2E+01	4.9E+02	2.3E+00	6.4E-02	Magnesium (Ecoinvent - estimation 1998)
Manganese		3.1E+00	2.8E-02	1.2E-02	4.7E-08	6.7E-03	5.3E-07	4.1E-03	6.1E-02	1.1E-02	9.4E-03	4.8E-06	4.9E+01	7.8E+01	n.a	n.a	Ferro manganese - primary (PE - 2000)
Mercury		1.2E+02	8.8E-01	2.5E-01	1.5E-05	2.3E-01	1.7E-04	7.3E-02	1.8E+00	5.9E+01	4.6E+03	1.0E-01	1.6E+03	4.3E+02	7.9E-02	1.9E-01	Mercury liquid (Ecoinvent - estimation 2000)
Molybdenum		1.1E+01	2.0E-01	1.9E-01	5.9E-07	2.9E-01	2.8E-04	8.5E-02	3.0E+00	6.0E+00	1.3E+00	4.6E-02	1.3E+02	7.9E+02	6.2E-01	9.0E+00	Molybdenum (Ecoinvent - 2003)
Nickel		6.9E+00	7.2E+00	5.0E-01	6.9E-07	1.2E+00	1.1E-04	4.9E-03	4.7E-01	2.5E+01	6.3E-02	9.1E-05	8.5E+01	3.8E+02	1.3E-01	1.5E-01	Nickel primary (combined production from Platinum) (ecoinvent - 2002)

Table A2.1. (Continue) Specific environmental impacts of materials (per kg)

Material	Impact category	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication fresh water	Aquatic eutrophication marine water	Human toxicirty	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Water consumption	Agricultural land occupation	Urban land occupation	
	Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil	Freshwater	ALOP	ULOP	
[1 kg]	Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ	kg	m2*yr	m2*yr	
Perlite		1.0E+00	3.1E-03	2.0E-03	2.4E-07	9.6E-04	4.2E-06	6.8E-04	1.3E-02	2.3E-02	2.2E-03	1.1E-06	1.4E+01	2.0E+01	2.0E-02	7.8E-03	Expanded perlite (ecoinvent - 2000)
Phosphate		6.2E-02	4.5E-04	2.1E-04	3.2E-09	1.2E-04	4.2E-08	7.0E-05	9.8E-04	2.0E-04	1.1E-04	9.2E-07	7.0E-01	6.7E-01	n.a	n.a	Phosphate rock mining (PE - 2005)
Platinum (PGM *)		1.5E+04	1.5E+04	1.1E+03	1.5E-03	2.6E+03	2.4E-01	1.1E+01	1.0E+03	5.3E+04	1.3E+02	2.5E+00	1.8E+05	8.2E+05	2.8E+02	3.1E+02	Platinum primary (Ecoinvent - 2002)
Potash		2.4E+00	8.9E-03	4.7E-03	1.9E-07	2.9E-03	2.2E-05	1.6E-03	6.0E-02	2.0E-01	2.2E-02	1.3E-05	3.1E+01	9.7E+01	5.4E-02	2.6E-02	Potassium carbonate (Ecoinvent - 2006)
Rare Earth (*)		5.0E+01	3.0E-01	1.1E-01	8.0E-06	9.2E-02	3.5E-03	3.4E-02	7.6E+00	5.1E+00	6.4E-01	4.6E-04	9.4E+02	1.8E+03	1.4E+00	4.2E-01	94% rare earth oxide (Ecoinvent - estimation 2005)
Salt		9.1E-02	7.7E-04	1.2E-03	4.0E-09	3.4E-04	1.4E-07	4.4E-04	1.5E-03	1.3E-04	5.4E-05	1.6E-05	1.2E+00	1.4E-01	n.a	n.a	Sodium chloride (PE - 2005)
Silica-sand		3.1E-01	5.1E-04	3.6E-04	4.5E-08	1.4E-04	2.5E-07	1.3E-04	3.5E-03	3.7E-04	2.0E-04	1.0E-08	3.0E+00	2.6E+00	n.a	n.a	Silica sand (PE - 2005)
Selenium		2.8E+00	9.8E-02	1.2E-02	1.1E-06	1.8E-02	8.4E-05	2.7E-03	3.4E-01	3.4E-01	4.7E-02	5.5E-05	3.7E+01	2.1E+02	1.3E-01	2.8E-02	Selenium (Ecoinvent - estimation 2000)
Silicon		8.1E+00	3.6E-02	2.3E-02	9.6E-07	9.3E-03	2.0E-06	8.2E-03	5.7E-02	9.7E-03	4.5E-03	2.2E-06	5.8E+01	4.1E+01	n.a	n.a	Silicon (average technology mix) (PE - 2000)
Silver		4.5E+02	6.2E+00	4.9E+00	3.6E-05	2.1E+00	4.3E-03	1.8E+00	3.5E+01	1.8E+02	5.1E+00	1.4E+00	5.5E+03	1.2E+04	6.4E+00	7.1E+01	Silver from combined production (Ecoinvent - 2004)
Sulphur		5.5E-01	3.2E-03	1.3E-03	1.6E-08	6.7E-04	4.6E-06	3.9E-04	3.7E-02	6.9E-03	2.9E-03	4.9E-08	3.1E+01	6.2E-02	n.a	n.a	Sulphur (from crude oil) ELCD - 2003
Talc		4.1E-01	2.7E-03	1.8E-03	1.3E-07	7.6E-04	4.1E-07	6.5E-04	7.4E-03	1.3E-03	4.7E-04	4.3E-08	4.2E+00	2.9E+00	n.a	n.a	Talcum powder (PE - 2005)
Tantalum (*)		2.9E+02	1.9E+00	1.6E+00	2.1E-05	1.2E+00	5.3E-03	5.8E-01	7.8E+00	3.0E+01	2.1E+00	1.4E-03	3.5E+03	1.4E+04	1.6E+01	6.4E+01	Tantalum powder in capacitors (Ecoinvent - 2003)
Tellurium		7.9E+00	3.0E-01	5.6E-02	4.3E-07	8.3E-02	9.7E-05	1.6E-02	1.3E+00	3.3E+00	1.1E+00	5.7E-01	1.0E+02	3.5E+02	2.0E-01	1.2E+00	Tellurium Semiconductor grade (Ecoinvent - 2005)
Tin		3.2E+00	9.9E-03	6.0E-03	2.4E-07	2.2E-03	4.8E-05	1.8E-03	1.3E-01	8.5E-02	1.3E-03	7.2E-08	3.7E+00	n.a	n.a	n.a	Tin plate primary (BUWAL - 1996)
Titanium		4.7E+00	3.6E-02	1.5E-02	7.7E-07	1.3E-02	1.4E-04	5.0E-03	1.4E-01	9.2E-01	2.9E-02	1.7E-05	6.6E+01	1.5E+02	6.0E-02	2.4E-02	Titanium dioxide (Ecoinvent - 2000)
Zinc		3.4E+00	4.6E-02	1.9E-02	1.6E-07	1.3E-02	2.2E-05	7.0E-03	1.9E-01	2.5E-01	2.0E-01	6.5E-04	4.3E+01	1.4E+02	7.0E-02	9.9E-02	Zinc primary (Ecoinvent - 2000)

Table A2.2. Specific environmental impacts of polymers (per kg)

Material	Impact category	Climate change	Acidification	Photochemical ozone	Ozone depletion	Respiratory effects	Aquatic eutrophication fresh water	Aquatic eutrophication marine water	Human toxicirty	Freshwater Acquatic Ecotoxicity	Terrestric ecotoxicity	Abiotic Depletion - elements	Abiotic Depletion - fossil fuels	Water consumption	Agricultural land occupation	Urban land occupation	Note and references
	Indicator	GWP	AP	POFP	ODP	PMFP	FEP	MEP	HTP	FAETP	TETP	ADP elements	ADP fossil	Freshwater	ALOP	ULOP	
[1 kg]	Unit	kg CO2-eq.	kg SO2-eq.	kg NMVOC-eq	kg CFC11-eq.	kg PM10-eq	kg P-eq	kg N-eq	kg 1,4-DCB	kg DCB-eq.	kg DCB-eq.	kg Sb-eq.	MJ	kg	m2*yr	m2*yr	
ABS		3.8E+00	1.2E-02	6.7E-03	n.a	2.8E-03	1.2E-04	2.5E-03	9.5E-04	2.6E-03	3.9E-03	1.5E-06	8.0E+01	1.2E+02	n.a	n.a	ABS granulate (ELCD - 1996)
EPS		3.4E+00	1.1E-02	6.2E-03	n.a	2.6E-03	7.2E-05	2.0E-03	1.0E-03	4.1E-03	9.4E-03	3.5E-07	7.5E+01	1.6E+02	n.a	n.a	Polystyrene expandable granulate (EPS) (ELCD - 2003)
HDPE		2.0E+00	6.6E-03	4.3E-03	n.a	1.5E-03	4.0E-07	1.3E-03	4.9E-04	1.7E-01	7.8E-05	2.7E-08	6.3E+01	1.9E+01	n.a	n.a	Polyethylene high density granulate (PE-HD) (ELCd - 1999)
LDPE and LLDPE		2.1E+00	8.0E-03	4.5E-03	n.a	1.8E-03	5.2E-07	1.5E-03	7.0E-04	1.1E-03	1.1E-04	2.2E-07	6.2E+01	3.4E+01	n.a	n.a	Polyethylene low density granulate (PE-LD) (ELCD - 1999)
PA		8.0E+00	2.9E-02	1.6E-02	n.a	6.8E-03	7.7E-04	1.4E-02	2.5E-03	5.0E-02	4.3E-03	3.3E-06	1.1E+02	5.4E+02	n.a	n.a	Nylon 6.6 granulate (PA 6.6) (ELCD - 1996)
PC		7.8E+00	2.5E-02	1.4E-02	n.a	5.8E-03	2.3E-04	4.7E-03	2.3E-03	2.4E-02	2.9E-02	1.4E-05	8.7E+01	7.6E+01	n.a	n.a	Polycarbonate granulate (PC) (ELCD - 1996)
PET		3.3E+00	1.6E-02	8.7E-03	n.a	3.6E-03	1.1E-07	2.9E-03	1.6E-03	4.6E-03	1.2E-02	4.9E-08	6.4E+01	5.4E+01	n.a	n.a	Polyethylene terephthalate granulate (PET, amorph) (ELCD - 1999)
PP		2.0E+00	6.2E-03	4.0E-03	n.a	1.5E-03	9.6E-05	1.3E-03	4.0E-04	5.6E-04	5.9E-05	4.6E-08	6.2E+01	3.4E+01	n.a	n.a	Polypropylene granulate (PP) (ELCD - 1999)
PS		4.4E+00	2.2E-02	9.7E-03	n.a	4.7E-03	7.4E-05	3.1E-03	1.4E-03	4.3E-03	9.6E-03	4.2E-07	8.8E+01	1.9E+02	n.a	n.a	Polystyrene part (PS) (ELCD - 2005)
PUR		4.3E+00	1.8E-02	1.2E-02	2.0E-08	7.1E-03	2.3E-04	4.9E-03	1.3E-01	1.9E-01	1.4E-02	2.3E-05	7.8E+01	3.5E+02	1.8E-02	4.2E-03	polyurethane, rigid foam (Ecoinvent - 1997)

Annex 3 - Analysis of end-uses of relevant materials

Table A3.1. End-uses of relevant materials

Materials	Details and End-uses
Copper	<u>End-uses (market sectors):</u> Construction (23.0%); Electrical equipment (28.0%); Electronics (13.0%); equipment manufacturing (12.0%); road transport (10.0%); Other transport (4.0%); Others (10.0%). Detail of market sectors: - *Building Construction* - Building Wire; Plumbing & Heating; Air Conditioning & Commercial Refrigeration; Builders Hardware; Architectural - *Electrical and Electronic Products* - Power Utilities; Telecommunications; Business Electronics; Lighting & Wiring Devices - *Industrial Machinery and Equipment* - In-Plant Equipment; Industrial Valves & Fittings; Non-Electrical Instruments; Off-Highway Vehicles; Heat Exchangers - *Transportation Equipment*: automobile; truck & bus; railroad; marine; aircraft & aerospace - *Consumer and General Products* - Appliances; Military & Commercial; Consumer Electronics; Fasteners & Closures; Coinage; Utensils & Cutlery; Miscellaneous <u>Detail of end-uses:(data for USA 2009):</u> Building Wire (23.6%); Strip, Sheet, Plate and Foil (brass) (13.9%); Tube and Pipe (brass) (12.4%); Rod and Bar and mechanical wire (brass) (11.4%); Magnet Wire (8.0%); Power Cable (7.1%); Automotive Wire and Cable (except Magnet) (4.8%); Telecommunications Cable (3.5%); Bare Wire (3.4%); Foundry Products (3.2%); Electronic Wire and Cable (3.1%); Apparatus Wire and Cordage (2.0%); Other Insulated Wire and Cable (0.9%) ; Powder Products (0.5%); Imports of Mill Products (2.2%) <u>Data sources</u>: - European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials - Annual Data 2011 – Copper, Brass, Bronze 1990-2010. Copper Supply and consumption. Copper Development association (http://www.copper.org/resources/market_data/pdfs/annual_data.pdf)
Platinum (PGM *)	<u>End-uses:</u> Auto catalyst (53.0%); Jewellery (20.0%); Electric and electronics (11.0%); Dental alloys (6.0%); Catalysts: Chemicals (6.0%); Glass making equipment (2.0%); Catalyst for petroleum (1.0%); Other uses (1.0%) <u>Platinum into auto catalyst:</u> Catalytic converters for vehicles require PGMs to maximize their performance. Catalytic converters are a pollution abatement technology whose main purpose is to reduce the amount of harmful emissions from an internal combustion engine. If an automobile burned fuel with perfect efficiency, then its only exhaust products would be carbon dioxide, nitrogen gas, and water. Because combustion is not perfectly efficient, however, automobiles often emit carbon monoxide, hydrocarbons, and nitrogen oxides into the atmosphere. By passing the automobile exhaust through a catalytic converter (a heated honeycomb-tube structure coated with a porous ceramic embedded with the PGM catalysts palladium, platinum and/or rhodium), about 95 percent of these pollutants can be converted to other substances. <u>Platinum into electronics</u> PGMs, primarily palladium, platinum, and ruthenium, have become important materials for performance of critical components in computers and other electronic devices. Major uses for PGMs in the electrical and electronics sector include components in capacitors and resistors (palladium), computer storage disks (platinum), electrodes, fuel cells, and thermocouples. Thermocouples are the single leading use for platinum in the electrical/electronics sector. Platinum alloys and platinum-rhodium alloys are used as electrical-resistance heating elements in such applications as cigarette lighters, hot wire ignition systems, and nylon cutters, as sealing devices, and as windings for muffler furnaces. Palladium and palladium alloys are widely used in capacitors, connectors, and electrical contacts. PGMs are also used in carbon monoxide detectors, electrochemical sensors in automobiles, and medical devices In the electronics industry, PGMs have substituted for gold in electronic contacts […]. The main uses for palladium in the electronics sector are in multilayered ceramic capacitors (MLCC), thick film hybrid integrated circuits, plating connectors, and lead frames. More recently, platinum-coated data storage hard drive disks have become common. <u>Platinum in Fuel Cells</u> Platinum use related to fuel cells may change dramatically during the next several years. Research and application of fuel cell technology that uses hydrogen as a fuel to produce energy is expected to increase

	dramatically. Data sources: - European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials - USGS: Platinum-Group Metals—World Supply and Demand http://pubs.usgs.gov/of/2004/1224/2004-1224.pdf
Iron	End-uses: Construction (26.0%); automotive (16.0%); Mechanical engineering (14.0%); tubes (12.0%); Metal goods (12.0%); Structural (11.0%); domestic appliances (4.0%); Shipyard (1.0%); Others (4.0%). Iron is the most widely used of all metals. Prior to its use, however, it must be treated in some way to improve its properties or it must be combined with one or more other elements to form an alloy. By far the most common alloy of iron is steel. 98% percent of iron ore are used for the manufacture of iron and steel. The remaining 2% are used, for example, for dyes and chemicals. Some of the industries, among others, that require iron and steel are the construction industry for steel framing of large buildings, construction of railways, shipbuilding industry, car industry, construction of pipelines. Data sources: - European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials
Gold	End-uses: Jewellery and arts (69.0%); electrical and electronics (9.0%); dental (9.0%); other (13%) End-use details: Gold's great virtues of malleability, ductility, reflectivity, resistance to corrosion and unparalleled ability as a thermal and electrical conductor mean it is used in a wide variety of industrial applications The major application of gold in electronics is the plating of contacts in switches, relays and connectors. Gold's other main role in electronics is in semiconductor devices, where fine gold wire or strip is used to connect parts such as transistors and integrated circuits, and in printed circuit boards to link components. Bonding wire is one of the most specialized uses of gold; it is highly refined to 99.99% purity and the wire has a typical diameter of one hundredth of a millimetre. Gold's malleability and resistance to corrosion render it suitable for dental use, although its softness means that it must be alloyed to retard wear. The most common companion metals are platinum, silver and copper. Other applications for gold include decorative plating (electroplating) of products. Gold has many uses in the production of glass. The most basic use in glassmaking is that of a pigment. A small amount of gold suspended in the glass when it is annealed produces a rich ruby colour. Gold is also used when making specialty glass for climate controlled buildings and cases Data sources: US Geological Survey http://www.ereport.ru/en/articles/commod/gold.htm
Silver	End-uses: Main applications of silver are in the production of jewels, coins and silver electroplated wares. The physical properties of silver include ductility, electrical- and thermal conductivity, malleability and reflectivity. For industrial applications, owing to silver's properties, silver is used in: - conductors, - contacts, - fuses, - timers, and - switches. Silver is also used to make solder and brazing alloys, electrical contacts, and high capacity silver-zinc and silver-cadmium batteries. Other industrial applications of silver included: - uses in conductive adhesives; - in the preparation of thick film, - silver-palladium pastes for use as silkscreen circuit paths in multilayer ceramic capacitors; - in the manufacture of membrane switches; - in flat screen televisions with plasma display panels; - in silver-backed solar mirrors; - as a film in electrically heated automobile windows; - in smart cards; - in photovoltaic cells (especially thick-film applications), The malleability, non-toxicity and beauty of silver make it useful in dental alloys for fittings and fillings. Silver was one of the essential materials used in the manufacture of films and photographic papers. The decline in the use of silver for photography began in 2000 in response to digital camera. Data sources: US Geological Survey

Aluminium	End-uses: Various sectors, including automotive and transport, building, and packaging, are all able to take advantage of the various properties of aluminium, such as light weight, high reflectivity, flexibility, and efficiency in protecting goods and preventing food spoilage. End-uses of aluminium in Europe (2009) are: - Transport: 30% (e.g. automobiles, aircraft, trucks, railway, marine vessels, bicycles) - Building 29% (e.g. lading, windows, skylights, gutters, door frames, and roofing) - Packaging 20% (e.g. drinks cans, foil wrappings, bottle tops and foil containers) - Engineering 14% (e.g. pipes, tubes, casting, sheet, electrical transmission lines, outer shells and cases of electronics and equipment, substrates) - Other 7% Data sources: EEA: http://www.alueurope.eu/pdf/EAA_activity_report_2010_V10_2.pdf
Magnesium (*)	End-uses: Magnesium is the most lightweight metals and it is used were weight saving is a premium (especially transportation and packaging). Aluminium alloying is currently the principal use for primary magnesium, followed by die-casting and iron and steel desulfurization. Other uses are for sacrificial anodes and metallurgical processing, aerospace applications, power tools and sport goods. Data sources: US Geological Survey British Geological survey
Chromium	End-uses: Most chromium is consumed in the metallurgical industry to produce stainless steel. The stainless steel shipment quantities divided by their sum are the distribution of chromium among metallurgical markets. These include (data refer to USA 2000): - Service industry: 60% (wholesale trade, durable goods; metal service centres) - Transportation: 27% - Fabricated products: 27% (forgings, industrial fasteners, appliances, utensils, containers, packaging, and shipping, military) - Machinery: 9% (construction; oil and gas industry; mining, quarrying, lumbering; agriculture; industrial equipment; domestic and commercial equipment) - Electrical equipment: 1% Chromium is used as an alloying element to produce a variety of nonferrous alloys including aluminium-, cobalt-, copper-, iron-, nickel-, and titanium-base alloys. Chromium is also used to produce chromium-containing chemicals for refractory applications. Data sources: Chromium use by market in the united states. http://www.pyrometallurgy.co.za/InfaconX/015.pdf
Polyurethane (PUR)	End-uses: With the diverse range of high performance properties, polyurethanes (PURs) are essential to a multitude of end-use applications, including (USA 2004): Building & Construction 26.8%; Transportation 23.8%; Furniture & Bedding 20.7%; Appliances 5.1%; Packaging 4.6%; Textiles, Fibres & Apparel 3.3%; Machinery & Foundry 3.3%; Electronics 1.4%; Footwear 0.7%; Other 10.2% Polyurethane can be found in different forms: in liquid coatings and paints, tough elastomers, rigid insulation for buildings, soft flexible foam in mattresses and automotive seats or as an integral skin in sports goods. Data sources: American Chemistry Council: www.polyurethane.org/s_api/bin.asp?CID=867&DID=3746&DOC=FILE.PDF
Zinc	End-uses: End uses of Zinc are: Galvanization: 46.0%; Brass & bronze 18.0%; Zinc-based alloys (mainly to supply the die casting industry) 14.0%; Chemicals (zinc oxide and zinc sulphate used for the production of rubbers and pharmaceuticals) 10.0%; Zinc semi-manufactures (rolled zinc for roofing, gutters and down-pipes; wire, pipes) 10.0%; Other 2.0% One of the biggest uses of zinc is in making protective coatings for steel. Zinc will corrode preferentially to give cathodic protection to iron. This is used to good effect to protect immersed structures. Zinc is also largely used for the production of brass and bronze (see information on copper). Data sources: - European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials - U.S. Geological Survey

	- International Zinc association
Salt (NaCl)	End-uses: Main application of salt (NaCl) are: Chemical industry (40.0%); Road de-icing (38.0%); distributors (8.0%); food (4.0%); agricultural (4.0%); general industrial (2.0%); water treatment (2.0%); others (2.0%) The industrial uses of salt are diverse and include: - Oil and gas exploration. Salt is an important component of drilling fluids in well drilling. - Textiles and dyeing. Salt is used as a brine rinse to separate organic contaminants, to promote "salting out" of dyestuff precipitates, and to blend with concentrated dyes. - Pulp and paper. Salt is used to bleach wood pulp. It also is used to make sodium chlorate, which is added along with sulphuric acid and water to manufacture chlorine dioxide, an excellent oxygen-based bleaching chemical - Metal processing. Salt is used in concentrating uranium ore into uranium oxide (yellow cake). It also is used in processing aluminium, beryllium, copper, steel, and vanadium. - Tanning and leather treatment. Salt is added to animal hides to inhibit microbial activity on the underside of the hides and to attract moisture back into the hides - Rubber manufacture. Salt is used to make neoprene and white types. Salt brine and sulphuric acid are used to coagulate emulsified latex made from chlorinated butadiene. Data sources: U.S. Geological Survey. http://minerals.usgs.gov/minerals/pubs/commodity/salt/myb1-2009-salt.pdf
PE-HD	End-uses: Blow moulding is the largest end use, accounting for 28 percent of total demand in 2005. Film represents the next largest segment with 26 percent market share. Other significant end uses are injection moulding (19 percent) and pipe and conduit (13 percent). Other applications are production of fibres (5%), other extruded products (5%) and other applications (4 %.) Data sources: Chemsystem webpage: http://www.chemsystems.com/about/cs/news/items/PERP%20HDPE%20REPORT.cfm
Molybdenum	End-uses: - *Stainless steel*. Stainless grades containing molybdenum are widely used including in pharmaceutical, pulp and paper and chemical plants, tanker trucks, ocean-going tankers and desalination plants. - *Engineering steel*. Molybdenum is usually present in alloy steel used in pipelines and drilling equipment in the oil and gas sector - *Molybdenum alloys*. It is used for machines that make tools and the tools themselves, drill tools and cutting and shaping edges containing. - *Superalloy*. Superalloy containing molybdenum is often used in jet and rocket engines, power-generating turbines, turbochargers and chemical and petroleum plants. - *Cast iron*. Molybdenum adds strength and hardness and helps cast iron tolerate the high pressures and temperatures of modern diesel engines. - *Molybdenum metal*. Molybdenum as a pure metal is used frequently in small quantities, including use as a powder coating for other metals. It is also a component of wiring and connections in electronics, light bulbs, and the coating sprayed in solar cells and flat panel displays - *Chemicals*. Molybdenum is a key component of catalysts used by petroleum refineries to reduce the sulphur content of gasoline and diesel. Molybdenum disulfide has numerous properties that make it an efficient lubricant. Data sources: - European Commission - Annex V to the Report of the Ad-hoc Working Group on defining critical raw materials - Thompson Creek (www.thompsoncreekmetals.com/s/About_Moly.asp)
Polypropylene (PP)	End-uses: Main end-use of Polypropylene are: Injection moulding 36% ; fibres 23%; film and sheets 14%; blow moulding 1%; ropes 3%; Others 23% Injection moulding of PP is used to produce various house-ware, furniture, appliances, luggage, toys, battery cases and other "durable" items for home, garden or leisure use. Polypropylene is used for flexible packaging for film extrusion. The film market may be divided into three main sectors: food and confectioneries; tobacco; clothing Polypropylene is also used for rigid packaging. PP is blow moulded to produce bottles for the packaging of a range of products. Caps and closures manufactured of PP have benefited from growth in the PET bottle market.

	PP fibre is utilised in a host of applications including tape, strapping, bulk continuous filament, staple fibres and continuous filament. In the automotive sector PP is utilised as a mono-material solution for automotive interiors. In other industrial sectors, PP is used to manufacture a range of sheet, pipe, compounding and returnable Transport Packaging Data sources: - Alberta Industrial Heartland Association (www.albertacanada.com/documents/Alberta_PP_Report.pdf) - The British Plastics Federation (www.bpf.co.uk)
PE-LD , PE-LLD	End-uses: Low density and linear low density polyethylene (PE-LD and PE-LLD) are mainly used for the production of packaging. For example, this include almost all the usually transparent packaging film used for fresh and frozen vegetable bags, blanket packs, soft supermarket carry-out bags, fertilizer bags and dry cleaners film packaging, anti-shocking wrappings. Other typical end-use include soft, squeezable bottles, soft covers for fridge containers, the soft containers themselves and the softer varieties of black agricultural pipe. Small percentages of PE-LD and PE-LLD are also used in the building sector and into Electric and Electronic (e.g. into insulations of cables or heating pipes, roof insulations, barrier layers). Into the automotive sectors the PE-LD and PE-LLD are used for dashboards, door panels, consoles, boot interiors and handgrips. Data sources: ▪ The British Plastics Federation (www.bpf.co.uk) ▪ PlasticsEurope - The recycling and recovery of Polyolefins waste in Europe
Mercury	End-uses: ▪ Chlor-alkali plants (41.2%); ▪ Dental amalgams (23.5%); ▪ Chemical (10.2%); ▪ Batteries (3.8%) as Mercury oxide batteries; ▪ Lamps (3.1%) mainly into fluorescent tubes, compact fluorescent tubes, HID lamps, and lamps in electronics; ▪ Measurement equipment (2.8%), mainly medical thermometers, other mercury-in-glass thermometers, barometers and sphygmomanometers; ▪ Switches (0.1%) as tilt switches for all applications, thermo-regulators and relays; ▪ Others (15.3%) e.g. ‘Porosimetry’ and ‘pycnometry’, conductors in seam welding machines (mainly maintenance), mercury slip rings, Maintenance of lighthouses, Maintenance of bearings; Data sources: COWI - Options for reducing mercury use in products and applications, and the fate of mercury already circulating in society

Annex 4 – Analysis of potential case-study product groups

Table A4.1. Analysis of potential case-study product groups

Criteria		Product group					
		Air-conditioning and ventilation systems	**Heating equipment**	**Food-preparing equipment**	**Furnaces and ovens**	**Data processing and storing equipment**	**Refrigerating and freezing**
A.1	Relevance to policies	Included in the WP 2009-2011	Included in the WP 2009-11.	Included in the WP 2009-11.	Included in the WP 2009-11.	Included in the WP 2009-11.	Included in the WP 2009-11. (IM developed for domestic refrigerators)
B.2	Relevance for "RRR" Req.	Mostly constituted by recyclable materials. Disassembly at EoL potentially relevant. No evidence for reuse.	Mostly constituted by recyclable materials. Disassembly at EoL potentially relevant. No evidence for reuse.	Difficult to establish (broad product group). Plastic and metal recycling potentially relevant	Metal recycling potentially relevant. Dismantlind of special glass needed	Difficult to establish due to the large variety of the product group. Recycling of some metals potentially relevant	Large quantities of plastics and metals potentially recyclable/ recoverable. Examples of remanufacturing detected.
B.3	Relevance for "recycled content" Req.	Plastics (mainly PP) account for about 15%.	Low quantities of plastics	Large quantities of plastics generally used	Low quantities of plastics are used, but large quantities of glass	Low quantities of plastics	Large quantities of plastics and glass accounted.
B.4	Relevance for "use of priority materials" Req.	Some relevant materials into electronic components and compressors	Relevant quantity of copper (up to 10%). Few quantities of stainless steel and galvanized steel.	Estimated low use of some relevant materials (steels, copper)	Presence of copper into various component and stainless steel.	Use of relevant materials into electronic components (copper, precious metals, etc.)	Presence of some copper and steels into various components.
B.5	Relevance for "use of hazardous substances" Req.	Potetial hazardous substances into plastics and electronics	No information about use of hazardous substances	No information about use of hazardous substances	No information about use of haz subst. (except for capacitors into microwave oven)	Hazardous substances potentially present into electronic components	Potetial hazardous substances into plastics and electronics
B.6	Relevance for "durability" Req.	Product with a long useful life; design for maintenance can sensibly affect performance	Product with a long useful life; design for maintenance can sensibly affect performance	Low relevance of maintenance (especially for households)	Durability potentially relevant (especially for large appliances)	It is assumed that durability has a low relevance due to the general low technical life of the product	Product with a potential long useful life; design for maintenance can sensibly affect performance
C.7	Data availability	Preparatory study available. Few LCA publication on the sector. No data on disassembly.	Preparatory study available. Few LCA publication on the sector. No data disassembly.	Few data available	Preparatory study available. Few LCA publication on the sector. No data on disassembly.	Few data available	Preparatory study available. Some LCA publication on the sector. No data on disassembly.
C.8	Computational complexity	Complexity of data required and their modeling	No particular difficulties foreseen	Broad product group (various technologies in use)	No particular difficulties foreseen	Broad product group. High complexity of the products	Medium complexity of the product.

Legend

Orange	Suitable for the criterion
Yellow	Potentially suitable for the criterion
White	Not suitable for the criterion

Table A4.1 (continue).Analysis of potential case-study product groups

Criteria		Product group					
		Machine tools	Imaging and sound & imaging equipments	Power transformers	Water-using equipment	Computers & monitors	Dishwasher / Washing machines
A.1	Relevance to policies	Included in the WP 2009-11.	Included in the WP 2009-11.	Included in the WP 2009-11.	Included in the WP 2009-11.	Product group covered during the transitional period	IM developed
B.2	Relevance for "RRR" Req.	Disassembly of recyclable materials relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Relevant the recycling and recovery of metals and oils. Reusing options not detected	Low relevance (disassembly not relevant)	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.
B.3	Relevance for "recycled content" Req.	Low relevance (several plastics detected by in low quantities)	Plastics represent a significant portion of product mass (even up to 40-50%)	Low relevance of recycled plastics. Potential use of recycled oils.	Very low content of plastics	Plastics can represent a significant portion of product mass (40-50%)	Plastics represent about 15% of product's mass. Small amounts of glass
B.4	Relevance for "use of priority materials" Req.	Broad product groups. Use of various critical raw materials and high impact substances detected (e.g. Copper and steels)	Several priority materials detected, including critical raw materials and various high impact materials.	Presence of copper (around 10%)	No priority materials detected	Several priority materials detected, including critical raw materials and various high impact materials.	Large amount of steels. Presence of copper
B.5	Relevance for "use of hazardous substances" Req.	Broad product groups. Hazardous substances used (oils, heavy metals)	Potetial hazardous substances into plastics and electronics	Use of potential hazardous substances (oils)	No information about use of hazardous substances	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics
B.6	Relevance for "durability" Req.	Product with a generally long useful life; design for maintenance can sensibly affect performance	Life-time of products not long. Products often discarded due to technological development. Product upgrade possible	Long life-time of products but maintenance generally not difficult	Product with a long useful life; but low relevance of maintenance	Life-time of products not long. Products often discarded due to technological development. Product upgrade possible	Product with a generally long useful life; design for maintenance can sensibly affect performance
C.7	Data availability	Preparatory study available. No data available on disassembly	Preparatory study available. Few data on disassembly (some available in the literature e.g. printers)	Preparatory study available. No data on disassembly. Data collection difficult	Data not available (but their collection is expected not difficult)	Preparatory study available. Some studies in the literature. No data on disassembly.	Preparatory study available. No data on disassembly. Possible cooperation with manufacturer
C.8	Computational complexity	Broad and complex product group	Complex product group (several components) with various technologies	Difficulties to estimate impacts of oils	No particular difficulties foreseen. Few data necessary	Very complex products (computer + monitors)	Products generally complex (several components).

Legend

(orange)	Suitable for the criterion
(yellow)	Potentially suitable for the criterion
(white)	Not suitable for the criterion

Table A4.1 (continue).Analysis of potential case-study product groups

Criteria		Product group					
		Laundry driers	Lighting ptoducts	Vacuum cleaners	Televisions	Set-top boxes	Electric motors (including pumps, circulators, fans)
A.1	Relevance to policies	IM close to be published	IM developed	Product group covered during the transitional period	IM developed	IM developed for simple set top boxes.	IM developed for electric motors and circulators (not developed for fans, pumps)
B.2	Relevance for "RRR" Req.	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Potential relevant for LED and CFL. Not relevant for halogens	Disassembly of recyclable/reusable components relevant. Reuse of components possible	Disassembly of recyclable/reusable components relevant. Reuse of components detected.	Potential relevant the recovery of some materials into electronics	Disassembly of recyclable/reusable components relevant.
B.3	Relevance for "recycled content" Req.	Plastics (mainly PP and ABS) around 20% in mass.	Small quantities of plastics detected. Glass generally used.	Product mainly made by various plastics (over 50% in mass).	Plastics and glass detected (their amount depends on the considered technology)	Large quantities of plastics detected (especially for simple set-top box)	Low content of plastics
B.4	Relevance for "use of priority materials" Req.	Relevant amount of steels. Low amount of copper. Relevant materials into electronics (5% in mass)	Use of critical raw materials and high impact materials detected.	No priority materials detected.	Use of critical raw materials and high impact materials detected.	Small use high impacts materials (copper).	Large amount of copper and steel used. Potential use also of critical raw materials (neodymium)
B.5	Relevance for "use of hazardous substances" Req.	Potetial hazardous substances into plastics and electronics	Potetial use of heavy metals and hazardous substances into plastics	Potetial hazardous substances into plastics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	No information about use of hazardous substances
B.6	Relevance for "durability" Req.	Product with a generally long useful life; design for maintenance can affect performance	Conservation of performances over the time is relevant. However maintenance is generally not relevant	Potential life-length very variable. Design for maintenance potentially relevant	Potential life-length very variable. Design for maintenance relevant	Life-time of products not long. Products often discarded due to technological development.	Potential life-length very variable. Design for maintenance relevant
C.7	Data availability	Preparatory study available. Few data available on disassembly	Preparatory study available (various LCA published).No data available on disassembly	Preparatory study available (some LCA published).Few data available on disassembly	Preparatory study available. No dat on disassembly. Possible cooperation with manufacturers	Preparatory study available. No data available on disassembly	Preparatory study available. No data available on disassembly
C.8	Computational complexity	Products generally complex (several components).	Uncertainties concerning new technologies (e.g. LED) and assessment of impacts of some hazardous (Hg in CFL)	No particular difficulties foreseen.	Potential complex for number of components and technologies	Products complex (several components).	No particular difficulties foreseen.

Legend

(orange)	Suitable for the criterion
(yellow)	Potentially suitable for the criterion
(white)	Not suitable for the criterion

Table A4.1 (continue).Analysis of potential case-study product groups

	Criteria	Product group External power supply	 Insulation for building	 Windows	 Lighting control	 Heating controls	 Detergents
A.1	Relevance to policies	IM developed	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14
B.2	Relevance for "RRR" Req.	Low relevance for recovery (except for critical materials and hazardous substances covered by other criteria)	Low relevance (more important the disassembly from building).Reuse generally not possible	potentially relevant (but related to the disassembly from the building). Reuse of components not detected	Low quantities of potential recoverable materials. No info about reuse	Low quantities of potential recoverable materials. No info about reuse	Not relevant
B.3	Relevance for "recycled content" Req.	Plastics used (as PC , ABS) for the casing.(30% in mass)	Plastics dominate some insulation (but not mineral-based ones)	Plastics (insulations) potentially relevant	Low relevant (small quantities of plastics used)	Low relevant (small quantities of plastics used)	Potentially relevant (use of the packaging)
B.4	Relevance for "use of priority materials" Req.	Critical raw materials (e.g. Lithium) and high impacts materials used.	No content of relevant materials detected	Potential relevant for the content of Aluminum and PVC	potential use of some relevant materials into electronic components	potential use of some relevant materials into electronic components	No content of relevant materials detected
B.5	Relevance for "use of hazardous substances" Req.	Potential use of hazardous substances (e.g. Into batteries and plastics)	No information about use of hazardous substances	No information about use of hazardous substances	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	No information about use of hazardous substances
B.6	Relevance for "durability" Req.	Life-time of products not long. No relevant options for extending life-time. Maintenance generally not relevant	Conservation of performances over the time is very relevant.	Conservation of performances over the time is very relevant.	Low relevance of maintenance	Low relevance of maintenance	Not relevant
C.7	Data availability	Preparatory study available. No data on disassembly. Possible cooperation with manufacturer	Preparatory study not available. Some LCA available. No data about disassembly	Preparatory study not available. Some LCA available. No data about disassembly	Low data availability	Low data availability	Low data availability
C.8	Computational complexity	No particular difficulties foreseen.	Difficulties to model the use phase	Very complex modeling of the use phase	Complex modeling (interaction with lighting systems)	Complex modeling (interaction with heating systems)	Difficulties to assess some impacts (Eutrophication) and interaction with cleaning of EuP

Legend

(orange)	Suitable for the criterion
(yellow)	Potentially suitable for the criterion
(white)	Not suitable for the criterion

Table A4.1 (continue).Analysis of potential case-study product groups

Criteria		Product group: Mobile power generation sets	Agricultural equipment	Elevators	Mobile phones	Electric kettles/cookers	Hot beverage equipment
A.1	Relevance to policies	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14
B.2	Relevance for "RRR" Req.	Disassembly of recyclable/reusable components potentially relevant. No info about reuse	Recovery of some components potential relevant (few data available, very broad product group).	Disassembly of recyclable/reusable components relevant (large amount of metals). Reuse of components generally difficult (security reasons).	Low relevance for recovery (except for critical materials and hazardous substances covered by other criteria)	Disassembly of recyclable/reusable components potentially relevant. No info about reuse	Disassembly of recyclable/reusable components potentially relevant. No info about reuse
B.3	Relevance for "recycled content" Req.	Plastics potential used for the external case	Plastic content generally not relevant	Low quantities of plastics detected	Low quantities of plastics generally used	Large amount of plastics generally used	Low quantities of plastics generally used
B.4	Relevance for "use of priority materials" Req.	Use of copper and magnets (similarly to electric motors)	Use of copper and other materials potentially relevant (very broad product group).	Use of copper and magnets (electric motor)	Use of critical raw materials and high impact materials detected	Use of copper and other relevant materials (in small electronic components when included)	Use of steels. Potential use of copper.
B.5	Relevance for "use of hazardous substances" Req.	No information about use of hazardous substances	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into plastics and electronics	Potetial hazardous substances into components (e.g. Batteries)	Potetial hazardous substances into plastics and electronics (when included)	No information about use of hazardous substances
B.6	Relevance for "durability" Req.	Potential life-length very variable. Design for maintenance relevant	Potential life-length very variable. Design for maintenance relevant	Potential life-length very variable. Design for maintenance relevant	Life-time of products not long. Products often discarded due to technological development.	Life-time of products not long.	Potential life-length very variable. Design for maintenance relevant
C.7	Data availability	No data available	No data available	No data available	Some LCA published Few data on disassembly available	Some LCA published Few data on disassembly available	No data available
C.8	Computational complexity	No particular difficulties foreseen.	Very broad product group	Product complex several components embodied)	Product complex (large varieties of equipments)	No particular difficulties foreseen.	Difficult to estimate (broad product group)

Legend

(orange)	Suitable for the criterion
(yellow)	Potentially suitable for the criterion
(white)	Not suitable for the criterion

Table A4.1 (continue).Analysis of potential case-study product groups

Criteria		Product group					
		Base station subsystems	Home audio products	Mobile construction machinery	PV panel	Packaging	Medical equipments
A.1	Relevance to policies	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Potential relevant for the WP 2012-14	Not included	Not included	Not included
B.2	Relevance for "RRR" Req.	Disassembly for reuse/recycle/recovery of some components potentially relevant (few data available - rough estimation)	Disassembly for reuse/recycle/recovery of some components potentially relevant (few data available - rough estimation)	Disassembly for reuse/recycle/recovery of some components potentially relevant (few data available - rough estimation)	Disassembly of some components for reuse/recycling/recovery potentially relevant (however few analysis available on the EoL of solar cell).	Disassembly for reuse/recycle/recovery potentially relevant (e.g. In food packaging)	Disassembly for reuse/recycle/recovery of some components potentially relevant (few data available - rough estimation)
B.3	Relevance for "recycled content" Req.	Low use of plastics (few data available - rough estimation)	Use of plastics potentially relevant (few data available - rough estimation)	Low use of plastics (few data available - rough estimation)	Few content of plastics. Glass used should have high transparency.	Very relevant due to the large amount of plastics	Plastics and glass generally used
B.4	Relevance for "use of priority materials" Req.	Potential use of various relevant materials and critical raw materials	Potential use of relevant materials (e.g. Copper) and critical raw materials	Potential use of relevant materials and critical raw materials (rough estimation due to the broad product group)	Large quantities of relevant materials and critical raw materials.	No information about use of relevant materials	Potential use of relevant materials into electronic components
B.5	Relevance for "use of hazardous substances" Req.	Potential use of hazardous substances (into batteries and electronic components)	Potential use of hazardous substances (into batteries and electronic components and flame retardant)	Potential use of hazardous substances (batteries, oils)	Potential use of hazardous substances (into electronic). Use of Cd in some technologies	No information about use of hazardous substances	Use of some hazardous substances possible (e.g. mercury, flame retardant)
B.6	Relevance for "durability" Req.	Long average useful life. Relevant maintenance of performances during the time	Life-time of products not long. Products often discarded due to technological development.	Life-time of products not long. Products often discarded due to technological development.	Long average useful life. Relevant maintenance of performances during the time	Low relevance	Long average useful life. Relevant maintenance of performances during the time
C.7	Data availability	No data available	No data available	No data available	Low data availability, especially about EoL. No data available on disassembly.	Few data available	No data available
C.8	Computational complexity	Very complex systems with several components (rough estimation due to few information available)	Broad product group. Products potentially complex (rough estimation due to few information available)	High complex systems. Broad product group (rough estimation due to few information available)	Very complex and uncertain modeling	No particular difficulties foreseen.	Products potentially complex. Broad product category

Legend

(orange)	Suitable for the criterion
(yellow)	Potentially suitable for the criterion
(white)	Not suitable for the criterion

Annex 5 –Measurement of the time for disassembly of product's components

The disassemblability of key parts has been identified as potentially relevant requirement on resource efficiency for some case-study products (e.g. washing machines and LCD-TV). The requirement would be based on the setting of a threshold for the disassembly time of the selected part. However, the enforcement and verification of the requirement would require the establishment of a detailed and standard procedure for the measurement of the time.

The procedure can be part of an international standard, to be developed involving all interested parties (manufacturers, recyclers, verification bodies). This annex presents some key issues to be considered in the standardisation process:

- minimum working experience of disassembler or operators should be set (e.g. number of years working in the sector);
- pre-conditions for the measurement may be defined (e.g. knowledge of the product's structure and location of the part to be disassembled, including access to relevant information from manufacturers as videos and exploded diagrams of the product);
- sequence of the steps of the disassembly;
- tools or machine/equipments to be used for the disassembly should be defined (e.g. common tools and machines in use in the recycling plants for dismantling);
- typology and precision of instruments used for measurement of the time should be set;
- uncertainty of the measurement should be assessed and the tolerance of the results should set.

Other elements to be considered are:

- product specificity of the standard (including the potential setting of a general standard for the measurements plus some additional product specific guidelines);
- stakeholders to be involved for the definition of the standard.

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Abstract:
The present applies and tests the developed methods for the assessment of some resource efficiency parameters (reusability/recyclability/recoverability-RRR, use of relevant resources, recycled content, use of hazardous substances, durability) on some representative and relevant case studies: imaging equipment (for recycled content); washing machines and LCD-TV (for RRR; use of relevant resources and use of hazardous substances)
The case-studies applications are followed by the identification and assessment of some ecodesign requirements potentially relevant at the case-study product level and at the product group level.

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