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Environmental Footprint and Material Efficiency Support for Product Policy

Report on benefits and impacts/costs of options for different potential material efficiency requirements for Dishwashers

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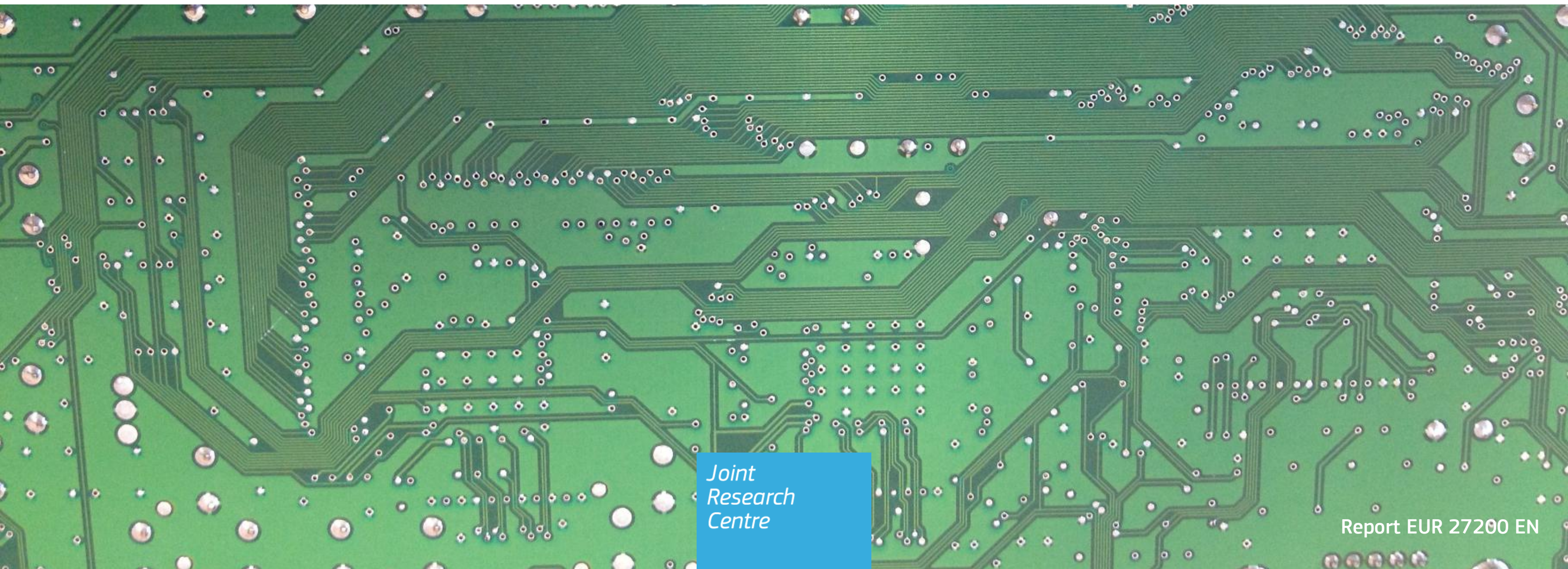

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Abstract:

The present report has been developed to support the European Commission in the integration in the Europea product policies of measures for the improvement of resource efficiency of products. In particular, the repor analyses potential requirements for dishwashers (DW) that can be implemented within the framework of th Ecodesign directive (2009/125/EC). The analysis is based on the application of the REAPro method to the dishwashe product group for the following resource efficiency criteria: reusability / recyclability / recoverability, recycle content, use of hazardous substances and durability.

The study concludes that the resource efficiency of dishwashers could significantly improve by the manual extractio of key parts before shredding, and also by extending the lifetime of a DW. On such purpose, the report propose some potential ecodesign measures.

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Executive Summary

The objective of the present report is supporting the European Commission for the integration in the European product policies of measures for the improvement of resource efficiency. In particular, the report analyses potential requirements for dishwashers (DW) that can be implemented within the framework of the Ecodesign directive (2009/125/EC). The analysis is based on the application of the REAPro method[1] to the DW product group for the following resource efficiency criteria: reusability / recyclability / recoverability, recycled content, use of hazardous substances and durability.

The first part of the report (Chapter 1) concerns a survey of the scientific literature to identify environmental studies of DW including relevant information for the end of life (EoL) analysis.

During this analysis, few information about detailed bill of materials (BoM) and EoL management of the DWs have been identified. As the content of ferrous metals is the main driver for the recycling of DW, data about materials contained in smaller amounts are imprecise.

Some available studies about the EoL of DW focused on comparing shredding with the manual disassembly of components with high content of copper. These studies show that separating parts with high content of copper before shredding help avoid copper losses and reduce its impurities in the recovered steel fractions thus improve the quality of steel.

Successively Chapter 2 presents the LCA of a representative DW, while Chapter 3 discusses the application of the REAPro method to the case-study. The report analyses the environmental impact of a 12 place setting DW for the two following EoL scenarios: shredding and combined treatments (preliminary dismantling with subsequent shredding). The analysis focuses initially on the recyclability and recoverability rate indexes[2]. Both indexes result very similar for the two scenarios because the different EoL treatments do not affect components with large mass.

The recyclability benefit rates[3] for the two EoL scenarios differ mainly for the impact categories “abiotic depletion potential elements (ADP_{el})” and “ecotoxicity”. Such differences (from 20% to 40%) are mainly due to the different recovery rates of copper, gold, palladium and silver when some key components (including pumps and printed circuit boards (PCBs)[4]) undergo directly shredding instead of being dismantled before.

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[1] F. Ardente, F. Mathieux. Refined methods and Guidance documents for the calculation of indices concerning Reusability/Recyclability/Recoverability, Recycled content, Use of Priority Resources, Use of Hazardous substances, Durability. JRC Technical Report n. 3 of the project “Integration of resource efficiency and waste management criteria in European product policies – Second phase”. November 2012 (http://lct.jrc.ec.europa.eu/assessment/projects#d).

[2] The reusability rate index is not analysed as no reusable parts were detected.

[3] The recyclability benefit rate is calculated for 13 different impact categories, as: abiotic depletion elements, abiotic depletion fossil, acidification potential, global warming potential, ozone layer depletion potential, terrestrial eutrophication, freshwater eutrophication, ionising radiation, marine eutrophication, particulate matter formation, photochemical oxidant formation, ecotoxicity and human toxicity.

[4] For instance, the recyclability benefit rate for ADP_{el} in scenario 1 is 39.5% whereas for scenario 2 is 77.4%. The recyclability benefit rate for the ecotoxicity impact category in scenario 1 is 31.1% whereas for scenario 2 is 54.1%.

The energy recoverability benefit rates[5] have very low difference (below 2%) in the two EoL scenarios, mainly because the share of energy recoverable at the EoL is very low compared to that used during the operating phase. The study continues with the analysis of the recycled content benefit index on polymer parts contained in the product[6]. The analysis shows that the potential benefits are not greater than 1% even when the amount of recycled PP reach up to 50%.

The analysis also concludes that, due to their potential content of hazardous substances as e.g. mercury, cadmium and other heavy metals, PCBs and liquid crystal displays (LCD), when present, should be extracted from DW before shredding in order to minimise the potential environmental impact of their improper recycling and ensure the best available end-of-life treatment.

Finally, lifetime issues have been assessed as relevant for the DW product group. For example, extending the lifetime of a DW by 4 years[7] can potentially grant the saving of 27% of the ADP_{el} impact, and other relevant benefits (around 20%) for other impacts categories as ecotoxicity and freshwater eutrophication[8]. The benefits for the other life cycle impact categories vary from 1% to 3%.

As a follow-up of the REAPro method, potential Ecodesign strategies to improve the resource efficiency of DW are discussed (Chapter 4) and the related environmental and economic benefits/costs have been estimated. Particular attention has been focused to the benefits related to the recovery of copper and precious metals.

The study concludes that the resource efficiency of dishwashers could significantly improve by the manual extraction of key parts before shredding, and also by extending the lifetime of a DW. On such purpose, the report proposes some potential ecodesign measures concerning:

- the time for extraction of PCBs larger than 10cm^2, LCDs screens and pumps shall not exceed 300 seconds;
- the design for durability the DW based on:
    - the reparability of some key components (including the availability of spare parts);
    - the setting of a minimum 2 years warranty for some key components (e.g. pumps, electronics, heating system and door panels).

This kind of requirements could be implemented in the context of the Ecodesign Directive when appropriate standards are developed.

It is estimated that the improved extractability of the key components will improve the EoL treatments of DW, increasing the recovery rate of copper and precious metals (as gold, palladium and silver). The implementation of the proposed requirement would allow the additional yearly

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[5] The energy recoverability benefits have been calculated only for “Abiotic depletion potential - fossil (ADP_{fossil})” because this is the impact category mainly influenced by this criterion.

[6] Due to the data availability, the analysis has been limited to the impact category “Abiotic depletion potential - fossil (ADP_{fossil})”.

[7] The calculation refers to the “low repairing” scenario, assuming to postpone the replacement with a 15% more energy efficient product.

[8] For the high repairing scenario, the potential benefit for the ADP_{el} impact category amounts to 13%.

recovery of about 1.031 tonnes of copper, 247 kg of silver, 50 kg of gold and 27 kg of palladium, which will have a potential economic benefit of 6.3 to 6.6 million €.

The improvement of the design for repairing and the extension of the warranty time of key components of the DWs could reduce up to 30% some life cycle environmental impacts, as abiotic depletion of elements (ADP_{el}), freshwater eutrophication and ecotoxicity.

Abbreviations

ADP el - Abiotic Depletion Potential element
ADP fossil - Abiotic Depletion Potential fossil
BoM – Bill of Materials
GER – Global Energy Requirement
DW - Dishwasher
EC – European Commission
EoL- End-of-Life
ErP – Energy Related Product
EuP – Energy Using Product
GER – Global Energy Requirement
GWP – Global Warming Potential
HRS – “high repairing” scenario
LCA – Life Cycle Assessment
LRS – “low repairing” scenario
MEEuP - Methodology for the Eco-design of Energy-using Products
PCB – Printed Circuit Board
POP - Persistent Organic Pollutants
PP - Polypropylene
PS – Place Settings
PM - Particulate Matter
RRR –Reusability / Recyclability / Recoverability
VOC - Volatile Organic Compounds
WEEE – Waste of Electrical and Electronic Equipment

Introduction

Environmental studies on home appliances, including dishwashers (DW), have assessed the relevance of energy and water use during the operating phase and have identified measures for their potential improvement [Scialdoni and Cutaia, 2007; Cutaia and Scialdoni, 2011]. These measures have been also applied to the EU product policies. For example the Ecodesign implementing measures for DWs[9] identified some energy, cleaning and drying efficiency indexes and define minimum thresholds for the performance of DWs to be placed in the market. These implementing measures however did not include requirements about the end of life (EoL) of DWs.

On the other hand, the past Ecolabel criteria on dishwashers[10] proposed also some relevant criteria on EoL aspects as: the provision by manufacturers of take-back services for DW; the need of marking certain plastic parts to improve their recycling; the limitation of the use of some potential hazardous substances (including some flame retardants in plastic parts); and the extension of warranty for the products. The Ecolabel criteria also proposed that manufacturers shall take into account the disassembly of DWs when designing and provide a disassembly report available to third parties on request.

According to the preparatory study for Ecodesign of DW [Scialdoni and Cutaia, 2007], the total number of household DW in the EU-27 was 70 million units in 2005. This means that there will be yearly about 61.7 thousand tonnes of copper, 5 tonnes of silver, 1.2 tonnes of gold and 0.6 tonnes of palladium stocked in waste DWs and potentially available for recycling. As the use of electronic components in DWs is still increasing, the amount of precious and scarce metals stocked in DWs and potentially recoverable can become even more significant in the next decade. The DW product group is therefore a relevant case-study for EU recycling facilities.

The present report is part of a series of studies of the Joint Research Centre (JRC) about the improvement of the resource efficiency of Energy-related Products (ErP) at the EoL and the implementation of potential EoL measures in Ecodesign implementing measures. These studies, based on the application of the REAPro method [Ardente and Mathieux, 2012; Ardente et Mathieux, 2014][11], highlighted that the implementation of such measures can lead for several product groups to great environmental and economic benefits, especially in terms of additional recycled materials[12]. This report summarises the application of the REAPro method to the dishwasher product group. It will identify and discuss resource efficiency measures for DWs which can help to improve current EoL treatments and bring some relevant economic and environmental benefits.

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[9] Commission Regulation (EU) No 1016/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers.

[10] Commission Decision of 28 August 2001 establishing ecological criteria for the award of the Community eco-label to dishwashers.

[11] Applications of the REAPro method are already available for television, washing machines and imaging equipment [Ardente and Mathieux, 2012b].

[12] For example, these studies identified that the design for extraction of some key components can increase the recovery yields of various critical, precious and scarce metals, and thus indirectly producing relevant life cycle environmental benefits.

The report starts with the environmental analysis of DW, as discussed in the scientific literature. The aim is to identify a representative case-study product (including a detailed bill of materials (BoM)) and representative European EoL scenarios.

Successively the case-study product will be analysed according to the REAPro method, and potential resource efficiency measures will be discussed and assessed.

1. Environmental Analysis of dishwashers

1.1 Introduction

The present chapter illustrates the environmental analysis of current commercialised dishwashers (DW).

The analysis is based on surveys and studies available in scientific and technical literature, including studies published using Life Cycle Assessment (LCA). It also provides strategies for the improvement of resource efficiency of DW.

1.2 Literature review

The following sections illustrate the review of the scientific and technical literature concerning environmental analyses of exemplary dishwashers. In particular, the review focused on available LCA and Ecodesign studies.

The Bill of Materials (BoM) of the analysed product are illustrated in Table 1.

Table 1 **Bills of Materials (BoM) of various exemplary dishwashers (from various references in the scientific literature)**

Materials	MEEuP methodology and case-studies		Preparatory study (DW 9PS)s		Preparatory study (DW 12PS)s		Study of dishwashers in Sweden (partial BoM)		UNEP study on resource efficiency		Study of dishwashers in China	
	Mass [g]	Percentage [%]	Mass [g]	Percentage [%]	Mass [g]	Percentage [%]	Mass [g]	Percentage [%]	Mass [g]	Percentage [%]	Mass [g]	Percentage [%]
	[VHK, 2005]		[ISIS, 2007]		[ISIS, 2007]		[Johansson and Luttropp, 2009; Johansson and Bjorklund, 2011]		estimated from [UNEP. 2013]		[Zhifeng et al., 2012]	
METALS:												
Aluminium	390	0.7%	172	0.4%	269	0.6%	-	-	400	0.8%	200	0.6%
Brass	-	-	-	-	23	0.05%	-	-	100	0.2%	-	-
Copper	920	1.6%	398	1.0%	656	1.4%	- Circulation pump (700) - Drain pump (100) - Wiring (100) - Electronics (100)	2.9%	750	1.5%	415	1.3%
Cromium	-	-	-	-	71	0.1%	-	-	-	-	-	-
Ferrous metals (Iron, steel, galvanized steel, etc.)	- stainless steel (7,420) - steel (4,460) - banded steel (10,940)	38.9%	- stainless steel (6,866) - steel (13.411) - galvanized steel (504)	51.7%	- stainless steel (8,691) - steel (18,172) - galvanized steel (403)	56.6%	- stainless steel (20,000) - steel (10,000)	85.7%	- stainless steel (11,600) - steel (22,550)	68.3%	23,598	72.3%
Zinc	20	0.0%	7	0.02%	4	0.01%	-	-	-	-	6	0.02%
PLASTICS:												
ABS	870	1.5%	708	1.8%	751	1.6%	-	-	-	-	742	2.3%
EPDM - rubber	570	1.0%	433	1.1%	524	1.1%	-	-	800	1.6%	450	1.4%
EPS	1,018	1.7%	88	0.2%	40	0.1%	-	-	-	-	745	2.3%
PA	200	0.3%	172	0.4%	399	0.8%	-	-	-	-	168	0.5%
PBT polybutylene terephthalate	-	-	58	0.1%	35	0.1%	-	-	-	-	155	0.5%
PE	189	0.3%	178	0.4%	187	0.4%	-	-	-	-	180	0.55%
PMMA	-	-	10	0.02%	6	0.01%	-	-	-	-	12	0.04%
POM	-	-	191	0.5%	230	0.5%	-	-	-	-	178	0.5%
PP (various)	8,810	15.0%	5,026	12.5%	4,981	10.3%	-	-	-	-	5226	16.0%
PS	1,000	1.7%	367	0.9%	512	1.1%	-	-	-	-	358	1.1%
PU Foam - Insulation	-	-	3	0.01%	2	0.00%	-	-	-	-	-	-
PVC	660	1.1%	210	0.5%	403	0.8%	-	-	-	-	198	0.6%
Plastics (others)	390	0.7%	121	0.3%	268	0.6%	-	-	6300	12.6%	-	-
OTHERS:												
Adhesive	-	-	15	0.04%	10	0.02%	-	-	-	-	-	-
Bitumen	9,500	16.2%	5,043	12.5%	6,089	12.6%	-	-	-	-	-	-
Cables	-	-	503	1.3%	350	0.7%	-	-	750	1.5%	-	-
Concrete and inerts	6,310	10.7%	2,153	5.4%	1,263	2.6%	-	-	1400	2.8%	-	-
Cotton and noise absorbers	1,040	1.8%	565	1.4%	941	2.0%	-	-	-	-	-	-
Electronic, boards, switches, lamp, etc	410	0.7%	694	1.7%	447.5	0.9%	-	-	50	0.1%	-	-
Paper	431	0.7%	130	0.3%	206	0.4%	-	-	-	-	-	-
Resins	-	-	200	0.5%	120	0.2%	-	-	-	-	-	-
Thermostat	-	-	17	0.04%	10	0.02%	-	-	-	-	-	-
Wood	2,930	5.0%	1,928	4.8%	2,034	4.2%	-	-	1050	2.1%	-	-
Other organic	-	-	-	-	-	-	-	-	2650	5.3%	-	-
Others	220	0.4%	36	0.09%	59	0.1%	4,000	11.4%	1600	3.2%	-	-
Total	**58,698**		**40,207**		**48,157**		**35,000**		**50,000**		**32,631**	

1.2.1 MEEuP product case-studies – domestic dishwashers

The analysis of the environmental performances of dishwasher (DW) has been performed as an exemplary application of the “Methodology for the Eco-design of Energy-using Products – MEEuP” [VHK, 2005]. A 12 place setting dishwasher was selected and analysed (Bill of Materials – BoM - of the product is presented in Table 1) as representative of the product category.

The analysis identified the “use” phase as the most relevant for the impact categories of Global Energy Requirement (GER), Global Warming Potential (GWP), Eutrophication; Acidification and water consumption. The distribution and End-of-Life (EoL) are relevant for the categories Particulate Matter (PM), Persistent Organic Pollutants (POP) and Volatile Organic Compounds (VOC), while the production and EoL phases dominate the production of normal and hazardous waste respectively.

1.2.2 EU preparatory study of EuP - Domestic Washing machines and Dishwashers

In 2007, the preparatory study for Ecodesign requirements of EuP –Domestic Washing machines and Dishwashers analysed the environmental performances of different products, identifying their environmental hot spots and suggesting potential ecodesign requirements to minimise their current environmental impacts [ISIS, 2007; Cutaia and Scialdoni, 2011]. This study investigated two “base-case” dishwashers: one of 9-place settings and one of 12-place settings (PS[13]). The BoM of both products are presented in Table 1. The energy and water consumption ranges of the selected devices were:

- Dishwasher A: 12 Place settings (12PS):
    - Energy consumption [kWh/cycle]: 1.01 – 1.45
    - Water consumption [litre/cycle]: 9 – 20
- Dishwasher B: 9 Place settings (9PS):
    - Energy consumption [kWh/cycle]: 0.8 – 1.1
    - Water consumption [litre/cycle]: 10 - 19

Figure 1 shows the results of the Life Cycle Assessment (LCA) of a 12-place setting dishwasher. The study concluded that the use phase is the most relevant for some impact categories (e.g. GWP; GER; Eutrophication; water consumption), while the production of raw materials is relevant for other categories as, for example, the production of waste, emissions of heavy metals and persistent organic compounds. The transport stage is relevant for the emission of particulate, while the manufacturing is only important for the production of hazardous waste.

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[13] The 12- place setting (12 Ps) dishwashers represent about 82% of the models sold in 2005, followed by the 9-place setting (9 Ps) dishwashers that represent the 12,2% of the models [ISIS, 2007].

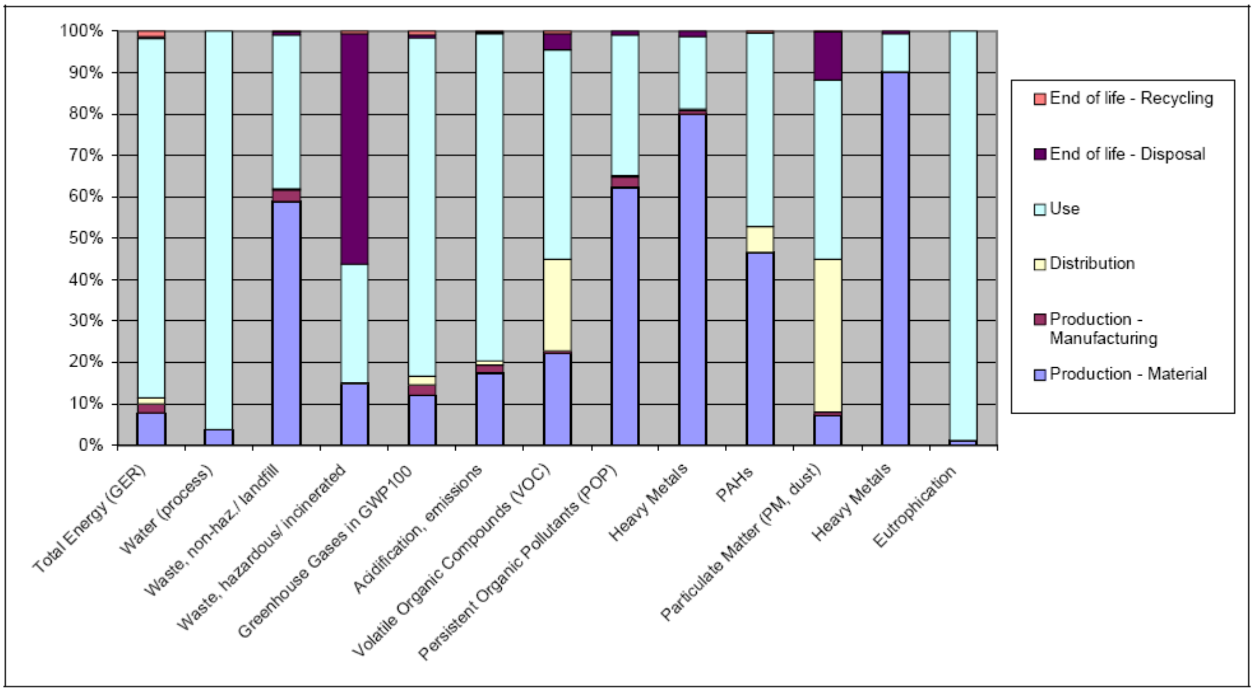


Figure 1 Life Cycle Impacts of dishwashers (12 PS) – percentage of the overall impact per different impact categories [ISIS, 2007]

According to the study, the contribution of the end-of-life stage to the overall environmental impact is generally negligible. However, the study also observes the large uncertainties of these results due to several EoL data missing, and also due to either too generic or incomplete information in some cases [ISIS, 2007].

The study identified the following aspects as highly relevant for potential Ecodesign requirements:

- Minimum washing performance
- Minimum drying performance
- Maximum energy consumption.

1.2.3 Study on improving the recycling of dishwashers

Johansson and Luttropp performed a study about EoL dismantling treatments of WEEE and introduced the concept of "material hygiene" for recycling [Johansson and Luttropp, 2009]:

> "Material hygiene is to, in every step of the product life cycle to act towards larger amounts and increased purity of useful material from recycling, possible to use on the same quality level as before or degraded as little as possible".

Johansson and Luttropp, 2009 make the assumption that operations done before shredding are beneficial for the recovery of materials. In particular "prior to shredding the important stage is dismantling. More careful dismantling leads to better recovery of material with less number of processing stages. In addition, dismantling by itself is a profitable process" [Manouchehri, 2005].

Dishwashers were chosen as an example of product family because of its relatively small number of components, the component similarity among diverse brands and models. Dishwashers contain largely the same type of features; the difference is mainly in the layout and assembly of these parts.

Fourteen dishwashers were selected as case-studies for the analysis. The disassembly study was conducted in a waste treatment plant in Stockholm (Sweden) in 2005. Dishwashers were all manually disassembled using only hand tools, e.g. screwdrivers and pliers.

One of the questions raised was: “is there a type (brand) of dishwasher in the current waste stream that has good recycling properties?”. The study selected copper as an example of relevant material for two main reasons: it is an economic valuable metal used widely for conducting electricity and heat, recovered in large amounts at present, and also because it may become an impurity when contained in small amounts in other metals as high grade steel. In addition, electronic scrap is the largest source of secondary copper [Bertram et al., 2002].

According to the study, a typical dishwasher contains approximately 1 kg of copper distributed in four subassemblies:

- Circulation pump motor (70%) – 700 g
- Drain pump motor (10%) – 100 g
- Wiring (10%) - 100 g
- Electronic components (10%) – 100 g

Johansson and Luttropp (2009) observed that the electrical motors are the parts containing the largest amount of copper. These parts are connected to other parts containing copper, i.e. the wiring and electronic components. Thus the assembly of the motor-circulation pump is a target part when planning possible disassembly operations of dishwashers.

According to the study, the design of dishwashers could roughly be divided into dishwashers that are designed to include a polymeric or metallic container and those that are not. The use of a polymer container with integrated pumps and motors seems to beneficiate manual or automatic disassembly operations as the parts containing large amount of copper are located within a short distance which allows extracting most of copper in one operation.

Figure 2 illustrates the copper outcome versus the time for manual dismantling. The dashed area represents the amount of copper and the time to dismantle all dishwashers under study. About 75% of the copper contained in dishwasher can be manually extracted in within 5 minutes. For some dishwashers, 5 min are not enough time to remove the motor which concentrates most of the copper. By improving their design, the time to prepare them for disassembly and extract the amount of copper contained can be reduced to approximately 2 minutes.

Figure 2 shows also three different case studies (A, B and C) which represent the following situations:

- Case study A: The circulation pump motor, drain pump motor and all wiring are removed. This means that about 95% of copper is removed, and only 5% is lost.
- Case study B: The circulation pump motor and part of wiring are removed. This means that 75% of copper is removed and thus 25% is lost;
- Case study C: The drain pump motor and part of wiring are removed. This means 25% of copper is removed whereas 75% is lost.

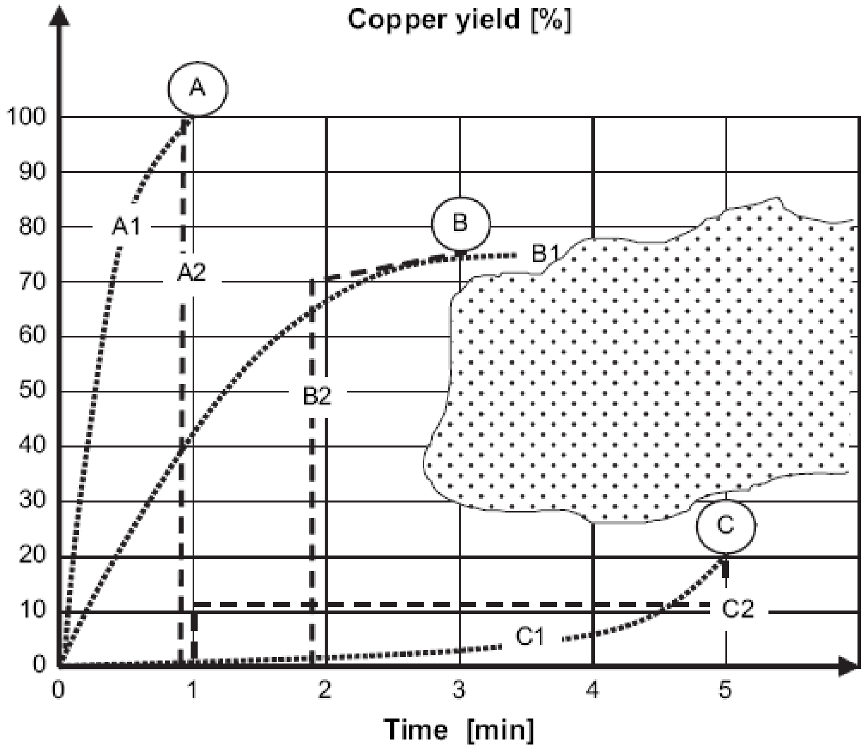


Figure 2 . Copper outcome versus time of manual work for disassembly. The dashed area between point B and C represents the analysed dishwashers. Points A, B and C, and the correlated outcome (100%, 75% and 20%) are defined to represent three exemplary typologies of dishwashers [Johansson and Luttropp, 2009]

Although the analysis has been specifically focused to copper recovery, authors conclude that a similar approach could be applied to the recovery of some other relevant materials and components in DW, and potentially, to other electrical and electronic waste.

1.2.4 Reducing the Life Cycle Environmental Impacts of WEEE

Johansson and Bjorklund (2011) estimated the environmental benefits of recycling copper contained in dishwashers based on the BoM presented by Johansson and Luttropp (2009). The environmental benefits of separating the circulation pump motor, the drain pump motor and all wiring were analysed by a simplified LCA. Figure 3 illustrates two possible EoL cases:

- Case 1: shredding-based process.
- Case 2: manual disassembly of components with high copper content before shredding.

Separating the parts with high content of copper before shredding may reduce (up to 40%) the results of abiotic depletion and global warming potential impact categories, and sensibly reduce copper impurities in the recovered steel fractions. Thus improve the quality of the steel recycled fraction (i.e. minimise the downcycling of steel).

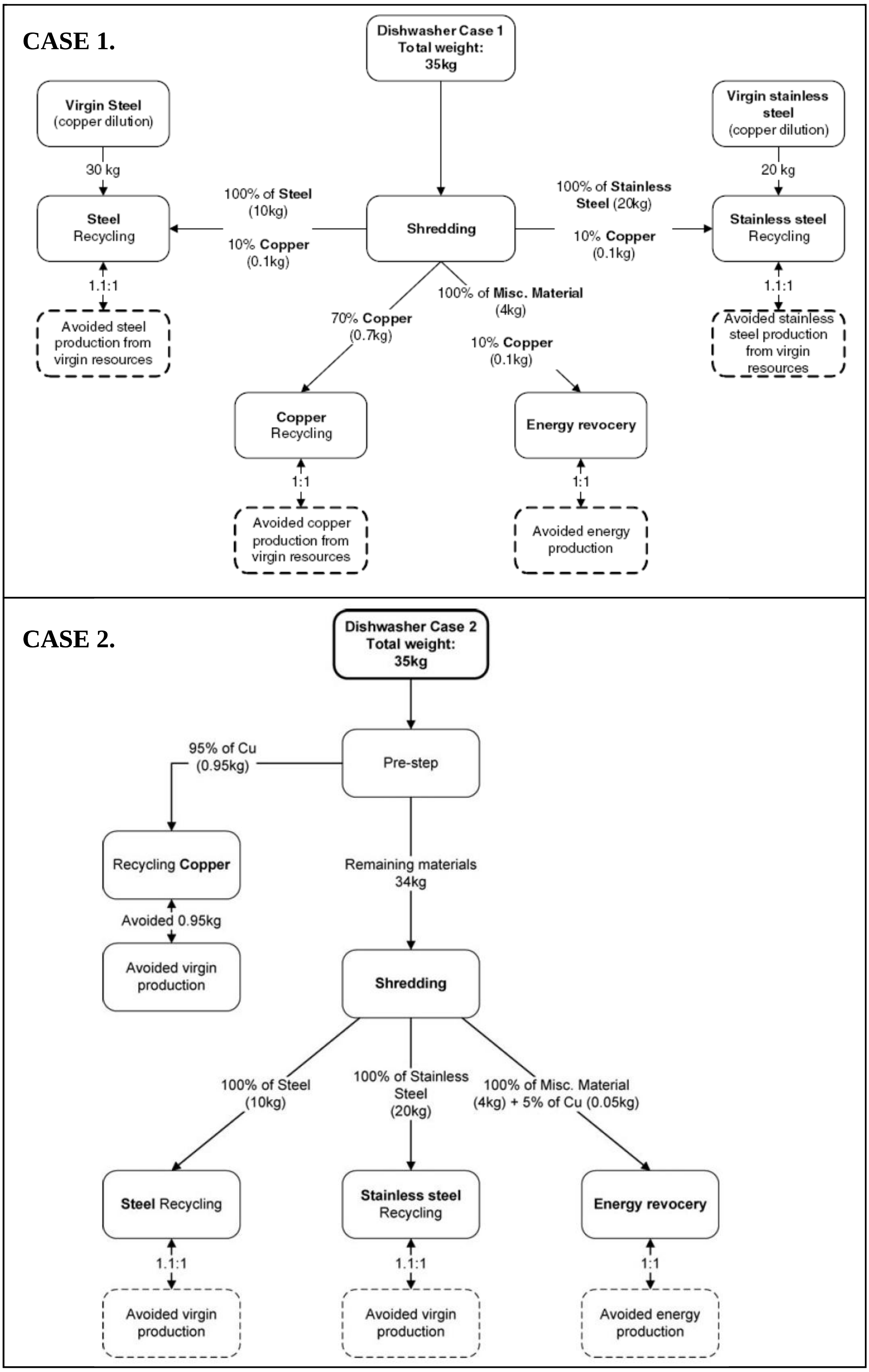
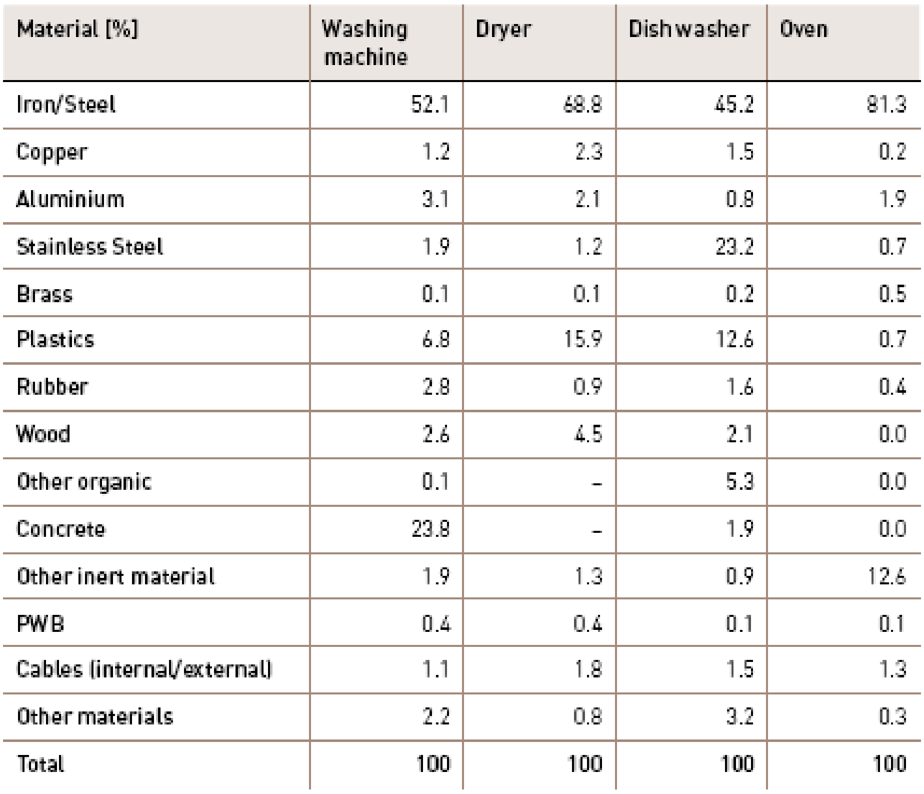


Figure 3 End-of-Life scenarios for the treatments of dishwashers and main flows of recycled materials [Johansson and Bjorklund, 2011]

1.2.5 Study on metal recycling: opportunities, limits and infrastructure

The UNEP has recently analysed the opportunities and limits of metal recycling, and how the resource efficiency of products can be improved [UNEP, 2013]. The study analysed the potential amount of materials that could be recycled from household equipment. Table 2 illustrates the average composition of washing machines, driers, dishwashers and ovens[14].

Table 2 Average composition of various exemplary "white goods" [UNEP, 2013]



Material [%]	Washing machine	Dryer	Dishwasher	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
Other 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**

The material composition and also the performance (especially during the use phase) of household appliances, including also white goods, vary notably from product to product. In general, high performing appliances use more complex electronic components, and thus have a greater variety of materials and their amounts.

The relevant materials contained in white goods are primarily present in Printed Circuit Boards (PCB). According to the UNEP's study, one tonne of PCBs of actual energy efficient white goods contain an average of:

- Silver (Ag): 160 g;
- Gold (Au): 38 g;
- Palladium (Pd): 20 g.

Usually the recycling of large white goods focuses on the recovery of commodity materials contained in greater amounts, as according to WEEE recycling guidelines. Concerning the PCBs the UNEP's study highlights that [UNEP, 2013]:

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[14] The values of Table 2 have been used to estimate an average BoM of DW, presented in Table 1 is (assuming an average mass of 50 kg .

- PCBs form a very small part of the streams of recycled materials, being mostly lost.
- If recovered, physics limits the production of clean recyclates from this, which makes subsequent process in metallurgical plants difficult.
- Recovery of materials from PCBs is generally regulated by the metallurgical processes that maximize the recovery of most relevant elements (e.g. those with the largest economic value).

Despite the thermodynamic limitations in the recovery of metals highlighted in the reports, there are still some strategies that can be adopted to improve recycling as for instance ‘design for recycling’ and ‘Design for Disassembly’ which is recognized as an “imperative to minimize loss of valuable elements to maximize profitability of the recycling system” [UNEP, 2013]. The design of components/subassemblies has a key impact on the efficiency of recycling/recovery. In particular, the recycling/recovery rate depends 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”.

1.2.6 Study on dishwasher’s environmental impact analysis and improvement

Zhifeng et al. (2012) recently published an LCA about the analysis of dishwashers in China. The objective was to study the environmental impacts associated with the production of raw materials, the manufacturing process and the recycling of a dishwasher in China, and help Chinese dishwasher manufacturing companies to address the requirements of the EU EUP directive [Zhifeng et al., 2012]. As already mentioned, Table 1 presents the BoM of the product studied, however information about electronic items contained in dishwasher is missing.

The considered EoL scenario (shown in Figure 4) assumes that dishwashers are delivered to a disassembly factory where the motor is manually dismantled, while the rest of the parts are mechanically sorted. Then, the metals are re-smelted for the production of raw materials, while the plastics contained are incinerated for energy recovery.

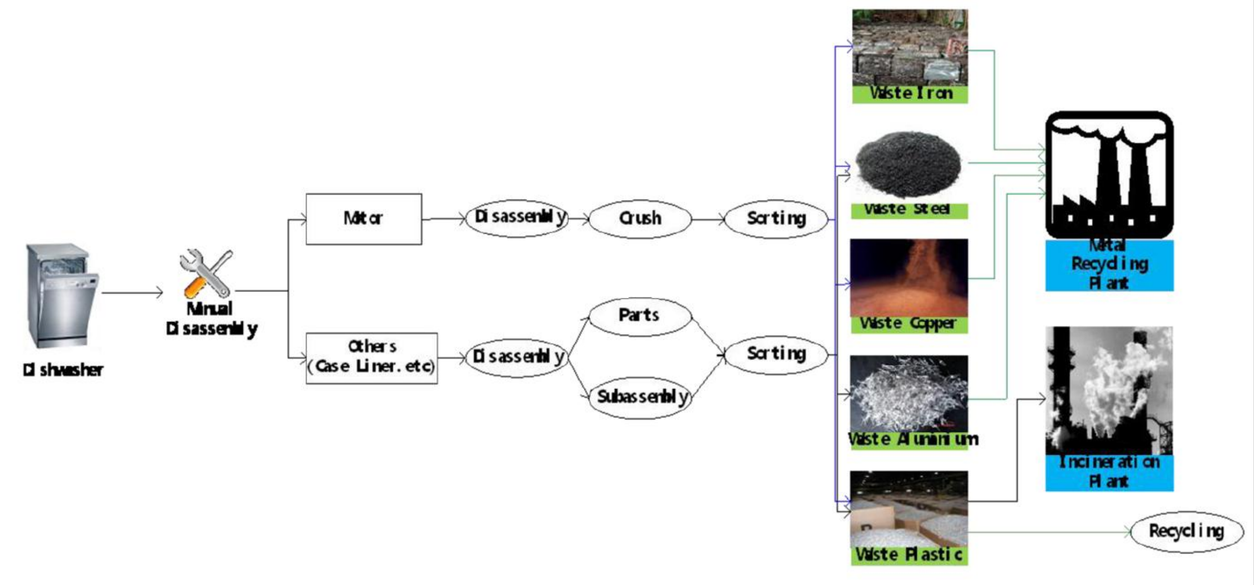

Figure 4 . End-of-Life scenario of dishwashers [Zhifeng et al., 2012]

The impact categories included in the LCA were: Acidification Potential (AP), Eutrophication Potential (EP), Freshwater Aquatic Ecotoxicity (FAE), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Marine Aquatic Ecotoxicity (MAE), Ozone Layer Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP) and Terrestrial Ecotoxicity Potential (TEP).

The results of the analysis, presented in Figure 5, conclude that the majority of the impacts are generated during the use phase (from 70% to 90% of the impacts) followed by the production of materials (from 10% to 30%). The other life cycle stages of the product generally account for less than 10%.

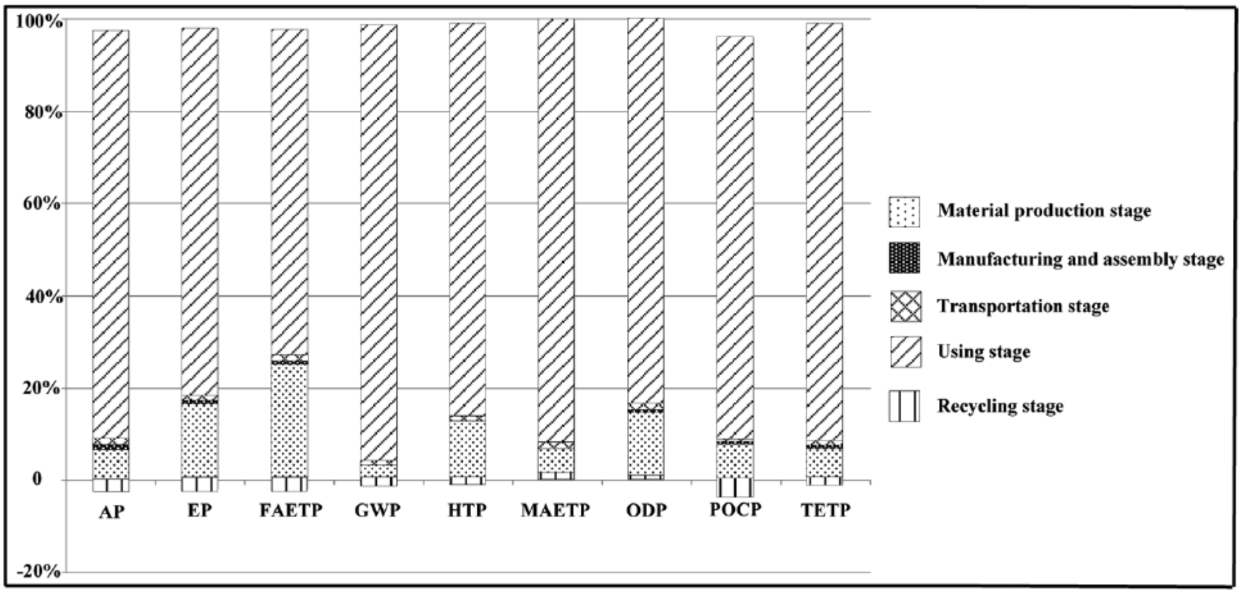

Figure 5 LCA of an exemplary dishwasher [Zhifeng et al., 2012]

The proposed measures to improve the current environmental performance are:

- The reduction of the energy consumption;
- The reduction of the water consumption;
- Provide detailed information in the user's manual[15].

These measures were all evaluated from cost, environmental performance and technical constraints.

1.2.7 Conclusions of the literature survey

The previous sections described the main environmental studies on dishwashers (DW) as published in the scientific literature, including environmental impact assessment using life cycle assessment (LCA), and the analysis of end-of-life (EoL) (with a special focus on the recovery of some relevant and economically valuable metals).

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[15] Information on the proper use of product are suggested, such as removing the plug after using dishwasher, use of the most efficient washing mode and installing the dishwasher in a proper work environment.

From these studies, there is no common view about life cycle impacts of the DW product group, as the study assumptions, the applied methodologies and the considered impact categories largely vary from one study to another.

For example, the MEEuP study concludes that the EoL has greater impact on the particulate matter (PM), persistent organic pollutants (POP) and volatile organic compounds (VOC) [VHK, 2005]. The preparatory study for Ecodesign requirements of EuP states that the contribution of the EoL to the overall environmental impact is negligible, partially due to data gaps [ISIS, 2007; Cutaia and Scialdoni, 2011]. Johansson and Bjorklund conclude that the disassembly of DW may reduce up to 40% abiotic depletion and global warming potential, and improve the quality of the steel recycled fraction [Johansson and Bjorklund 2011]. The results obtained by Zhifeng et al. show that the use phase generates from 70% to 90% of the environmental impacts being the remaining impact generated by the production of raw materials. The rest of life cycle stages, including the EoL have negligible impact [Zhifeng et al., 2012].

The results of the studies about the analysis of the potential recovery of valuable metals however are all aligned and highlight the importance of including design for disassembly and recycling aspects. Johansson and Luttropp conclude that dishwasher designed with a polymeric container with integrated pumps and motors beneficiate disassembly operations, as parts rich in copper are located within a short distance and can be extracted in one step operation [Johansson and Luttropp, 2009]. The study on metal recycling by UNEP conclude that PCBs contain the most economical relevant materials and points out that the design for disassembly and recycling help minimise losses of valuable elements and maximize profitability of recycling system [UNEP, 2013].

2. Selection and analysis of case-study dishwasher

2.1 Introduction

The present chapter illustrates the analysis of a case-study DW. First, it explains and illustrates the process followed to select the DW for the case-study and then it performs a LCA of the case study. The results of this analysis are used in the subsequent application of the REAPro method in the next chapters.

2.2 Case-study dishwasher: Bill-of-Materials

The diverse bill of materials (BoM) found during the literature review and included in table 1 show that BoM of DW is always dominated by the content of ferrous metals (mainly normal, galvanized and stainless steel), followed by the content of several plastics, mainly polypropylene. Due to the lack of information about the BoM of DW from manufacturing companies, we decided to analyze only one case-study. The BoM used for this case-study is based on the data given in the preparatory study for ecodesign of dishwashers [ISIS, 2007], which is assumed to be representative for the product group.

The analysis done in the previous survey in the literature showed a large variability in the material composition of some of the parts of a DW, for instance the electronics and copper-based components which happens to be the most relevant parts for the analysis of the material resource efficiency of ErP[16]. As result, we analysed in further detail the composition of these parts using other references (as from [Johansson and Luttropp, 2009; UNEP, 2013; IEC/TR 62635, 2012])[17].

The BoM of the base-case product for the present analysis of the DW has been derived from the preparatory study on dishwashers (DW 12 place settings as from Table 1)[18, 19] [ISIS, 2007], as it is considered as the most representative of the EU27 context. However, the application of the REAPro method requires some detailed information about the composition of some components[20]. Therefore, more detailed data on the composition of PCBs and the content of copper in pumps and cables, were taken from other specific studies(as summarized in Table 3):

- We assume that a DW contains two PCBs larger than 10 cm^2 (including capacitors). The content of precious metals (gold, silver and palladium) in PCB of white goods was based on [UNEP, 2013]

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[16] See [Ardente and Mathieux, 2012b].

[17] It is highlighted that also the preparatory study for ecodesign of DW accounts the general content of some components (as electric and electronics parts) in the DW, without providing details on their composition.

[18] According to the preparatory study for ecodesign of dishwashers [ISIS, 2007], this is the product with the largest share in the market.

[19] Packaging is excluded from the analysis.

[20] For instance, the preparatory study just points out the amount of Printed Circuit Boards (PCB) without any further detail on their composition.

whereas the content of the rest of metals contained is estimated from [Mohite, 2005; Mohite and Zhang, 2005]. The detailed composition of PCBs contained in DW is shown in Table 4.

- The content of copper in pumps was taken from [Johansson and Luttropp, 2009].
- For wiring and cables, we assume that 50% were internal and 50% were external. The content of copper in cables is estimated based on [IEC/TR 62635, 2012].

Table 3 Bill of materials of an exemplary dishwasher

Materials	**Dishwasher case-study (DW)**	
	Mass [g]	**Percentage [%]**
	[ISIS, 2007]	
METALS:		
Aluminium	268.6	0.6%
Brass	23.4	0.05%
Copper (in pumps)	- Circulation pump (560g) - Drain pump (96g)	1.4%
Chromium	71.3	0.1%
Ferrous metals	- stainless steel (8,691g) - steel (18,172g) - galvanized steel (403g)	56.6%
Zinc	4.2	0.01%
PLASTICS:		
ABS	751.3	1.6%
EPDM - rubber (pipes)	524.0	1.1%
EPS	39.7	0.1%
PA	398.6	0.8%
PBT polybutylene terephthalate	35.0	0.1%
PE	187.3	0.4%
PMMA	5.8	0.01%
POM	229.9	0.5%
PP (various)	4,980.6	10.3%
PS	511.5	1.1%
PU Foam - Insulation	2.4	0.00%
PVC	403.2	0.8%
Plastics (others)	267.9	0.6%
OTHERS:		
Adhesive	10.0	0.02%
Bitumen	6,089.0	12.6%
Cables	- Internal cables: copper 42g PVC 133g; - External cables: copper 57.8g; PVC 115.5g	0.7%
Concrete and inert	1,262.8	2.6%
Cotton and noise absorbers	941.2	2.0%
Electronics	2 PCBs (including capacitors): - Main PCB: 300g - Secondary: 147.5g	0.93%
Paper	205.5	0.4%
Resins	120.0	0.2%
Thermostat	10.0	0.02%
Wood	2,034.4	4.2%
Others	59.4	0.1%
Total	**48,157**	

Table 4 Average composition of PCBs (modified from [Mohite, 2005; Mohite and Zhang, 2005; UNEP, 2013])

Material	[%]
Antimony	0.02%
Aluminium	2.0%
Barium	0.42%
Beryllium	0.0001%
Cadmium	0.0003%
Cobalt	0.001%
Copper	28.0%
Gold	0.004%
Iron	3.2%
Lead	1.5%
Mercury	0.0001%
Nickel	0.56%
Palladium	0.002%
Silver	0.016%
Zinc	0.07%
Support (glass fibres, epoxy resin, ceramic, flame retardant TBBP-A): remaining percentages	

2.3 Calculation of the life cycle impacts of dishwasher

2.3.1 Goals and scope

The aim of this section is to evaluate the life cycle impacts of the selected base case-study for a DW (Table 3). The LCA was performed using Gabi 4 software [PE, 2012]. The results obtained will be used for calculating the indicators for reusability, recyclability, recoverability benefit rate and the durability according to the REAPro method, as defined in [Ardente and Mathieux, 2012].

2.3.2 Life cycle inventory

In order to perform the life cycle inventory of the DW under study, certain assumptions at different stages of the life cycle of DW were done:

- Assumption about the production of materials:
    - Bill of Materials: as in Table 3.
    - Life-Cycle-Inventory data of materials from various references [ecoinvent, 2007; ELCD, 2010; PE, 2012; BUWAL, 1996];
    - Energy consumption for the manufacturing of the PCBs estimated from [Williams, 2004];
    - Packaging is not included in the analysis.
    - The following materials were not included in the inventory analysis: antimony and beryllium (contained in PCB), some plastics as Polybutylene terephthalate (PBT),

polyoxymethylene (POM) the thermostat and other unspecified materials. All these materials account for less than 1.5% in mass of the product.

- Assumption about the manufacturing phase (energy and transport) as in [ISIS, 2007]:
    - the electricity use during assembling is 17,31 kWh at medium voltage:
    - the heat gas during assembling is 9,2 kWh
    - the transport for assembling by truck is 23 tkm
    - the transport for assembling by Sea ship is 10 tkm
- Assumptions about the use phase:
    - the consumption of electricity and water was based on [Zhifeng et al., 2012] (Table 5)[21, 22];
    - the transport to user equals 14.5 tkm by truck (estimation);
    - the consumption of cleaning agents and treatments of wastewaters were not considered in the analysis[23];

Table 5 Data on the electricity and water use of a DW during the use phase [Zhifeng et al., 2012]

Average life	12	years
Electricity consumption		
Time of one standard circulation	160	minutes
Power consumption of one standard cleaning circulation	0.822	kWh/cycle
Using frequency of one year	280	cycle/year
Standby energy consumption per hour	0.00245	kWh/hour
Standby time per year	204	hour/year
Shutdown energy consumption per hour	0.0003	kWh/hour
Shutdown time per year	7,810	hour/year
Overall yearly consumption	233.0	kWh/year
Overall consumption	2,796	kWh
Water consumption		
Water consumption of a standard circulation	13.5	litre/cycle
Overall consumption	45,360	litre

- Concerning impacts of EoL;
    - Inventory data about the landfill of metals, plastics and inert is based on [ELCD, 2010].

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[21] It is observed a substantial alignment to the assumptions of preparatory study on DW, which assumed: average life 12.5 years; energy consumption 2930 [kWh]; water consumption: 48,125 [litre].

[22] The consumption of detergents has been not considered due to the lack of inventory data for such materials.

[23] No life cycle inventory available about these phases.

- The transport of waste materials for EoL treatments is estimated to be 4.8 tkm by truck. The life-cycle inventory data of transport refers to [ELCD, 2010]);
- The impacts due to the sorting of materials was not considered[24].

2.3.3 Life cycle impact assessment

The life cycle impact assessment is based on a comprehensive set of impacts categories listed in Table 6[25]. The life cycle impacts of a DW are presented in Table 7 and Table 8. The impacts were sub-dived according to the following life cycle stages: Production of materials, Manufacturing, Use and Disposal.

Table 6 Environmental impact categories for the Life Cycle Impact Assessment (LCIA) (sources from [ILCD, 2011] unless differently specified in the notes)

Impact category	Selected LCIA method
Climate change	Global Warming Potential –(GWP$_{100}$)
Ozone depletion	Ozone Depletion Potential – (ODP)
Ecotoxicity (freshwater)	USEtox Ecotoxicity
Human toxicity effects	USEtox Human toxicity
Particulate matter	Particulate Matter Formation Potential (PMFP)[26]
Ionizing radiation	Human health effect model
Photochemical ozone formation	LOTUS-EUROS model
Acidification	CML - Acidification Potential (AP)[27]
Eutrophication	- Freshwater Eutrophication EUTREND (as in ReCiPe) - Marine Eutrophication EUTREND (as in ReCiPe) - Terrestrial Eutrophication[28]
Resource depletion	- CML Abiotic Depletion Potential fossil (ADP$_{fossil}$) - CML Abiotic Depletion Potential element (ADP$_{el}$)

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[24] 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.

[25] Life cycle impact indicators have been selected according to the recommendations of the European Commission “International Reference Life Cycle Data System – ILCD” [ILCD, 2011]. However, some impact categories as acidification, terrestrial Eutrophication and particulate matters have been relatively recently developed and are not fully implemented in LCA software. Other replaceable relevant life cycle indicators have been selected according to [ILCD, 2011]. For the “land use” and “water scarcity” impact categories no indicators have been selected.

[26] ReCiPe Midpoint impact category about Particulate matter formation (in PM_{10eq}.) as in software GaBi4 [PE, 2012].

[27] CML Acidification Potential as in software GaBi4 [PE, 2012].

[28] EDIP method for Terrestrial Eutrophication as in software GaBi4 [PE, 2012].

Table 7 Life Cycle Impact Assessment of the case-study DW (absolute values)

		Materials	Manufacturing	Use	Disposal
Abiotic Depletion (ADP elements)	[kg $Sb_{Equiv.}$]	3.1E-03	8.5E-07	1.4E-04	1.8E-06
Abiotic Depletion (ADP fossil)	[MJ]	1.1E+03	1.4E+02	1.6E+04	2.5E+01
Acidification Potential (AP)	[kg $SO_{2\text{-}Equiv.}$]	6.0E-01	8.4E-02	1.3E+01	8.3E-03
Global Warming Potential ($GWP_{100years}$)	[kg $CO_{2\text{-}Equiv.}$]	1.4E+02	1.3E+01	1.7E+03	6.2E+00
Ozone Layer Depletion Potential (ODP)	[kg $R11_{\text{-}Equiv.}$]	1.1E-05	2.4E-06	4.0E-04	8.1E-08
Terrestrial eutrophication	[m^2 UES]	6.0E+00	7.9E-01	7.7E+01	2.1E-01
Freshwater eutrophication	[kg P eq]	1.9E-03	1.6E-05	9.3E-04	1.4E-03
Ionising radiation	[kg $U_{235\ eq}$]	2.1E+06	2.7E+06	4.5E+08	9.5E+04
Marine eutrophication	[kg $N_{Equiv.}$]	9.1E-02	1.2E-02	1.2E+00	4.7E-03
Particulate matter formation	[kg $PM_{10\ eq}$]	2.1E-01	2.0E-02	2.8E+00	2.7E-03
Photochemical oxidant formation	[kg NMVOC]	2.9E-01	3.7E-02	3.9E+00	1.0E-02
Ecotoxicity	[PAF m^3.day]	1.8E+00	6.7E-03	5.2E-01	3.0E-03
Human toxicity	[cases]	1.9E-09	2.6E-10	3.0E-08	1.1E-10

Table 8 Life Cycle Impact Assessment of the case-study DW (relative values)

		Materials	Manufacturing	Use	Disposal
Abiotic Depletion (ADP elements)	[%]	95.6%	0.03%	4.3%	0.05%
Abiotic Depletion (ADP fossil)	[%]	6.4%	0.8%	92.7%	0.1%
Acidification Potential (AP)	[%]	4.5%	0.6%	94.9%	0.06%
Global Warming Potential ($GWP_{100years}$)	[%]	7.4%	0.7%	91.5%	0.3%
Ozone Layer Depletion Potential (ODP)	[%]	2.8%	0.6%	96.6%	0.02%
Terrestrial eutrophication	[%]	7.2%	0.9%	91.6%	0.25%
Freshwater eutrophication	[%]	44.8%	0.4%	22.4%	32.5%
Ionising radiation	[%]	0.5%	0.6%	98.9%	0.02%
Marine eutrophication	[%]	7.0%	0.9%	91.7%	0.36%
Particulate matter formation	[%]	7.0%	0.7%	92.2%	0.09%
Photochemical oxidant formation	[%]	6.9%	0.9%	92.0%	0.2%
Ecotoxicity	[%]	76.8%	0.3%	22.8%	0.1%
Human toxicity	[%]	5.9%	0.8%	93.0%	0.4%

Dominant (X > 60%)
Very relevant (30% < X < 60%)
Relevant (10% < X < 30%)
Low relevant (1% < X < 10%)
Not relevant (X < 1%)

The results of the analysis show that:

- The greatest potential environmental impact due to the production of materials is dominated by the Abiotic Depletion Potential – ADP_{el} (elements) and the Ecotoxicity categories, and followed by the freshwater Eutrophication. The environmental impact for the rest of the impact categories has low relevance.
- In the evaluation of the use phase, the results show that 10 out of the 12 impact categories evaluated have results above 90%, meaning that the potential environmental impact for these categories is extremely high. The impact categories with lower relevance are ADP_{el}, Ecotoxicity and freshwater Eutrophication.
- The environmental assessment of the disposal of a DW shows that only the ecotoxicity impact category is very relevant, mainly due to the impact of landfilling plastic parts[29].

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[29] Results according to inventory data for landfill of plastic mix (average) [ELCD, 2010]

- The environmental impact of the manufacturing phase is not relevant for any of the impact categories assessed.

A more detailed study about the “production of materials” (in Table 9) shows that the production of PCBs and other parts containing copper has a very relevant potential impact in the impact categories ADP_{el} and ecotoxicity, while the production of some parts of steel is highly significant for freshwater eutrophication. The large majority of the potential impacts related to PCBs are due to few substances, namely precious metals, copper and flame retardants.

The production of plastics, mainly polypropylene (PP) and polyethylene (PE) has a low relevance (up to 3%) for some impact categories (e.g. ADP_{fossil}, human toxicity and ecotoxicity), while the production of other metals like zinc, brass and chromium, is not relevant (always lower than 1%) for all the impact categories.

Table 9 Life Cycle Impact Assessment – detail of the “production of material” phase (percentage contribution to the overall life cycle impact)

		PCBs	Steel parts	Copper parts[1]
Abiotic Depletion (ADP elements)	[kg $Sb_{Equiv.}$]	44.0%	0.1%	45.1%
Freshwater eutrophication	[kg P eq]	0.7%	31.6%	0.03%
Ecotoxicity	[PAF m^3.day]	33.4%	0.8%	33.4%

[1] Not including copper in PCBs

3. Application of the REAPro method to an exemplary dishwasher case-study

3.1 Introduction

The present chapter illustrates the application of the "Resource Efficiency Assessment of Products – REAPro" method [Ardente and Mathieux, 2012] to a DW identified as a base case study in section 2.

First, the chapter presents the representative EoL scenarios for dishwashers, and then it shows how the indicators for Reusability / Recyclability / Recoverability – RRR - (in mass and environmental terms), Recycled content (in mass and environmental terms), use of hazardous substances and durability are calculated.

3.2 End-of-Life scenarios for the dishwasher product group

The end-of-Life (EoL) scenario for a considered product describes the treatments that the parts of the product will undergo at their EoL. The parts of a product are subdivided into [IEC/TR, 62635, 2012]: reusable parts[30]; parts for selective treatments[31]; parts for selective recycling[32]; parts difficult to process[33]; and other parts for material separation[34]. The EoL scenario has to be representative for the considered geographical context. In some cases, one or more scenarios could be relevant and representative. The setting of the EoL scenarios is based on references and feedback from recyclers.

The analysis of the EoL of DWs was based on the scientific and technical references previously identified and discussed in section 1 and 2, and communications from two recycling companies (one in Italy and one in Belgium). Two potential EoL scenarios were set as representative of the current EoL treatments: scenario 1) a shredding based scenario and scenario 2) which consists on a preliminary manual disassembly followed by one or more shredding phases, such treatment is hereafter referred as combined treatment [Johansson and Luttropp, 2009; Johansson and Bjorklund, 2011, Zhifeng et al., 2012].

Based on literature survey, we observed a large similarity between the treatments of DW with the treatments of washing machines (as discussed in [Ardente et Mathieux, 2012b]). In fact, recyclers, generally group these two product groups under the same category: "white goods".

For the analysis, we assumed that these two scenarios were equally representative of the treatment of waste flows of DW. The EoL scenarios of DW are presented in Figure 6.

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[30] Reusable parts disassembled for the re-manufacturing of new products.

[31] Parts that have to be diverted from waste flow for example, due to legislative requirements.

[32] Parts which are extracted/separated to be addressed to specific recycling/recovery treatments (e.g. valuable components, components with hazardous substances that could cause downcycling of other waste fractions).

[33] Parts that can cause problems to subsequent treatments in the recycling/recovery processes.

[34] Parts that are mechanically sorted (e.g. metal and plastic parts separated after fine shredding).

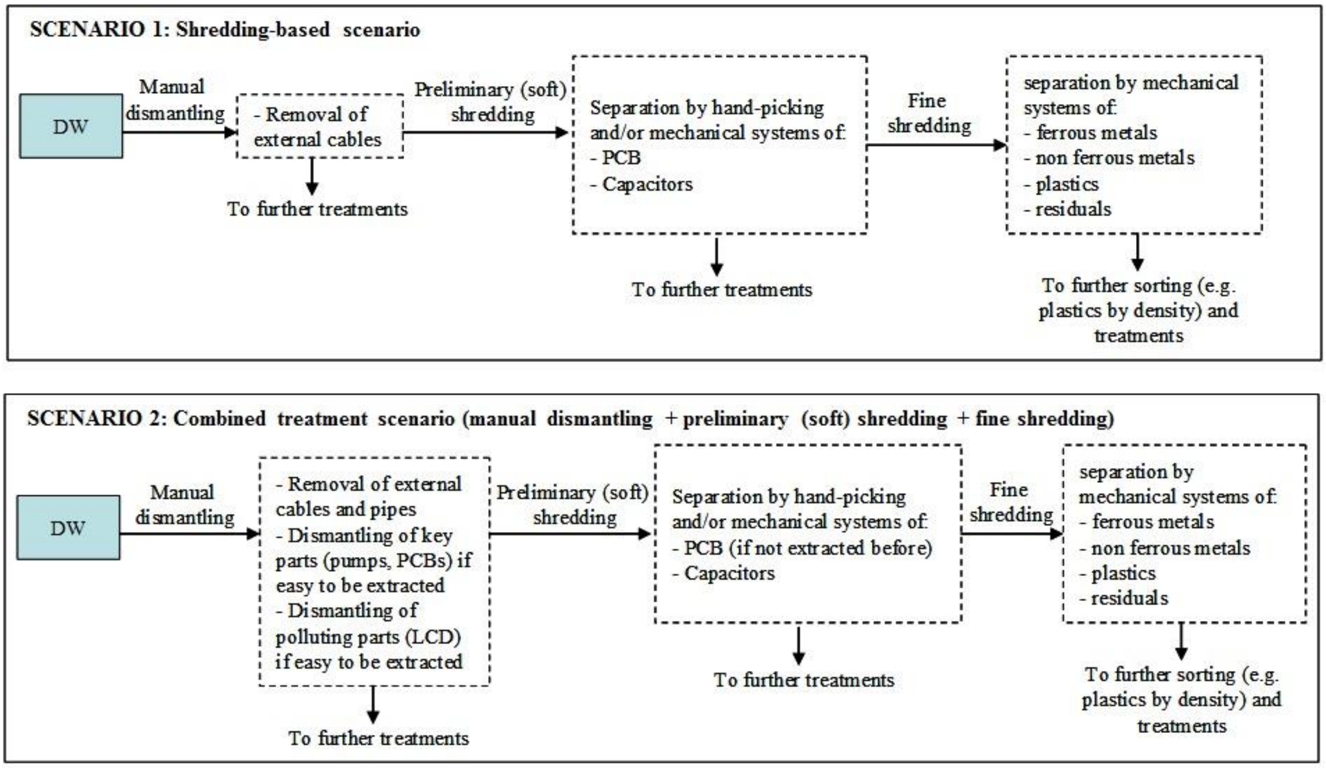

Figure 6 End-of-Life scenarios of dishwasher

3.3 Reusability/ Recyclability / Recoverability rate indexes (in mass)

3.3.1 Reusability rate index (in mass)

According to investigated references and interviewed recyclers, there are no evidences of components of DW currently extracted for re-manufacturing in the considered scenarios[35]. Thus the Reusability rate of the DW (R_{Use}) *is 0 %.*

3.3.2 Recyclability rate index (in mass)

The calculation of the Recyclability rate index - R^{*}_{cyc} - (in mass) is based on the identification of different typologies of product's parts, according to the set EoL scenario [Ardente and Mathieux, 2012].

For the combined treatment (scenario 2), we identified the following parts in the DW (Table 10):

a) Reusable parts

No reusable parts are identified (see also section 3.3.1).

b) Parts for selective treatments

These are parts that have to be removed according to the current legislation [EU, 2012] as:

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[35] We highlight that the method for the assessment of reusability considers only reusable parts for remanufacturing of new products. No end-of-life scenario aiming at putting second-hand products on the market has been considered in this analysis. Furthermore, the analysis of repairing old devices for prolonging the product's lifetime is part of the analysis on durability.

- external cables/wiring
- PCBs (greater than 10 cm^2),
- capacitors (higher than 2.5cm),
- LCD screens (liquid crystal displays) (greater than 100 cm^2 and all those back-lighted with gas discharge lamps).

PCBs can be removed preventively, by specific dismantling (when the time for dismantling is low[36]), or otherwise by other strategies (hand-picking or mechanical sorting) after preliminary and fine shredding. Capacitors, generally included in PCBs, are generally manually separated after the removal of PCBs.

External cables are removed without particular problems.

Large LCDs have to be removed before shredding. However, according to recycler, also smaller LCD in DW easy to dismantle are generally extracted to avoid the potential contamination of other recyclable fractions (mainly electronic parts) which can result in downcycling.

c) Parts for selective recycling

The parts for selective recycling include PCBs smaller than 10 cm^2 that are however, easy to be extracted, and parts rich in copper content (as the drain pump, circulation pump and internal cables). According to scientific literature, these parts are worth to be extracted before shredding to recover greater amount of metals thus maximizing resource efficiency and also its environmental benefits [Johansson and Luttropp, 2009; Johansson and Bjorklund, 2011]. The separation of the parts concentrating copper is also economically viable when the time for extraction is lower than 5 minutes [Johansson and Luttropp, 2009].

d) Parts difficult to process

- LCD screens, which could cause downcycling of other recyclable fractions as for instance indium
- External rubber pipes, which could interfere with some shredding plant[37].

e) Other parts

These parts are made of metals (separated for recycling after fine shredding and magnetic and non-magnetic separation), and plastics (sorted for partial recycling or recovery after fine shredding and mechanical systems, mainly based on density separators).

In the shredding based scenario (scenario 1), it is assumed that only external cables are preventively extracted, while other parts are all shredded and partially sorted, after the preliminary and fine shredding phases.

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[36] The threshold of the time for dismantling is set here according to communications from some recyclers, and in analogy to similar considerations for the washing machine case-study [Ardente et Mathieux, 2012b]. However, this time threshold has to be considered as exemplary for the case-study here presented.

[37] According to recyclers, rubber pipes could block small scale shredders (especially plants for the preliminary/soft shredding)

Table 10 Parts of the DW for the Recyclability and Recoverability rate indexes calculation

Part	Typology of part	Details and conditions for the treatments	Treatments
Parts to be re-used (if any)	Reusable part	- parts can be dismantled in a non-destructive way; - commercial reuse/refurbishment systems established	manual dismantling for reuse
PCB (larger than 10 cm^2)	Part for selective treatment	if T < 40 sec	manual dismantling for recycling
		otherwise	pre-shredding + handpicking/mechanical sorting for recycling
PCB (smaller than 10 cm^2)	Part for selective recycling	if T < 40 sec	manual dismantling for recycling
		otherwise	pre-shredding + handpicking/mechanical sorting for recycling
Capacitors	Part for selective treatment	if containing Polychlorobiphenyl or if larger than 2.5 cm diameter and if T <40 sec	manual dismantling for landfilling/incineration
	Part for selective treatment	otherwise	pre-shredding + handpicking for landfilling/incineration
LCD screens (if any)	Part for selective treatment	if surface >100 cm2 (or with backlighting systems)	manual dismantling for landfilling
	Part difficult to process	other LCD (if T<60 sec)	manual dismantling for landfilling
		other LCD (if T >60 sec)	pre-shredding + handpicking for landfilling
Circulation and drain pump (rich in copper)	Part for selective recycling	if T < 300 sec	manual dismantling for selective recycling
		if T > 300 sec	shredding + mechanical sorting
External electrical cables	Part for selective treatment	Extracted (no specific problems)	manual dismantling for selective recycling
Internal cables	Part for selective recycling	Extracted jointly to other parts (pumps) if these are dismantled	manual dismantling for selective recycling
	Other parts (for material separation)	Otherwise	shredded + mechanical separation for recycling or energy recovery
External pipes	Part difficult to process / Parts for material separation	(for some recycling plants, pipes can interfere with shredders)	manual dismantling for energy recovery or landfilling
Plastic parts	Other parts (for material separation)		shredded + mechanical separation for recycling or energy recovery
Other metal parts	Other parts (for material separation)		shredded + mechanical separation for recycling
Other materials (bitumen, wood)	Other parts (for material separation)		shredded + mechanical separation for landfilling

T = Time for dismantling

According to these assumptions, the Recyclability rate R^*_{cyc} (in mass) for the shredding based scenario (scenario 1) equals 66.7 % (full details are given in Table 12). The Recyclability rate (R^*_{cyc}) for the combined scenario (scenario 2) equals 67.2 % (full details are given in Table 12). The recyclability rate between the two scenarios is small mainly because the different treatments do not affect components with large mass (e.g. metal frameworks and plastic parts). The majority of material losses[38] for the recyclability index are due to the landfill of bitumen and wood parts and to the partial recovery of ferrous metals.

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[38] Losses for each component are calculated as: $\text{Losses} = \frac{(1 - \text{Recycling rate})}{\text{Product mass}} \cdot 100$ [%].

Table 11 Recyclability rate index (scenario 1: shredding)

Product Details					
Product	**Mass (m) of the product [g]**				
Dishwasher (DW)	48,157				
Parts for selective treatment:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
External cables	Copper and plastic (PVC)	175	33%	57.8	High current cable from IEC 62635. Copper recycled; PVC landfilled
Parts for selective recycling:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
Parts difficult to process:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
Other parts (for material separation):					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
Aluminium		268.6	91%	244.4	IEC 62635
Brass		23.4	70%	16.4	IEC 62635 (other metals)
Copper (pumps)		656.1	70%	459.3	Johansson and Bjorklund 2011
Chromium		71.3	70%	49.9	IEC 62635 (other metals)
Ferrous metals		27,266.0	94%	25630.0	IEC 62635 (steel general)
Zinc		4.2	70%	2.9	IEC 62635 (other metals)
ABS		751.3	74%	555.9	IEC 62635
External pipes (EPDM - rubber)		524.0	0%	0.0	IEC 62635 (other polymers)
EPS		39.7	0%	0.0	IEC 62635 (other polymers)
PA		398.6	0%	0.0	IEC 62635
PBT polybutylene terephthalate		35.0	0%	0.0	IEC 62635 (other polymers)
PE		187.3	90%	168.6	IEC 62635
PMMA		5.8	0%	0.0	IEC 62635 (other polymers)
POM		229.9	0%	0.0	IEC 62635 (other polymers)
PP (various)		4,980.6	90%	4482.6	IEC 62635
PS		511.5	83%	424.6	IEC 62635 (assumed as high impact polystyrene)
PU Foam - Insulation		2.4	0%	0.0	IEC 62635 (other polymers)
PVC		403.2	0%	0.0	IEC 62635 (other polymers)
Plastics (others)		267.9	0%	0.0	IEC 62635 (other polymers)
Adhesive		10.0	0%	0.0	no data available / unspecified
Bitumen		6,089.0	0%	0.0	no data available / unspecified
Cables internal (copper and PVC)		175.0	0%	0.0	estimation (based on communication of recyclers)
Concrete and inerts		1,262.8	0%	0.0	no data available / unspecified
Cotton and noise absorbers		941.2	0%	0.0	no data available / unspecified
Paper		205.5	0%	0.0	no data available / unspecified
PCBs (various)		447.5	8.5%	38.0	no data available (assumed 50% of PCB selectively treated as in IEC 62635)
Resins		120.0	0%	0.0	no data available / unspecified
Thermostat		10.0	0%	0.0	no data available / unspecified
Wood		2,034.4	0%	0.0	no data available / unspecified
Others		59.4	0%	0.0	no data available / unspecified
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [g]				**32,130**	
Recyclability rate ($R^{*}cyc$) [%]		**66.7%**			

Table 12 Recyclability rate index (scenario 2: combined treatment)

Product Details					
Product	**Mass (m) of the product [g]**				
Dishwasher (DW)	48,157				
Parts for selective treatment:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
External cables	Copper and plastic (PVC)	175	33%	57.8	High current cable from IEC 62635. Copper recycled; PVC landfilled
PCBs (includig capacitors)	Various materials	447.5	17%	76.1	IEC 62635 (PCBs intermediate)
Parts for selective recycling:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
Circulation Pump	Copper	560	95%	532.0	IEC 62635
Drain Pump	Copper	96	95%	91.2	IEC 62635
Internal cables		175	24%	42.0	IEC 62635 (low current cables assumed being extrated jointly with pumps)
Parts difficult to process:					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
External pipes	(EPDM - rubber)	524	0%	0.0	IEC 62635 (other polymers)
Other parts (for material separation):					
Parts and materials		**Mass ($m_{recycl,i}$) [g]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [g]**	**References/details for the (RCR)**
Aluminium		269	91%	244.4	IEC 62635
Brass		23	70%	16.4	IEC 62635 (other metals)
Cromium		71	70%	49.9	IEC 62635 (other metals)
Ferrous metals		27266	94%	25630.0	IEC 62635 (steel general)
Zinc		4.20	70%	2.9	IEC 62635 (other metals)
ABS		751	74%	555.9	IEC 62635
EPS		40	0%	0.0	IEC 62635 (other polymers)
PA		399	0%	0.0	IEC 62635
PBT polybutylene terephthalate		35	0%	0.0	IEC 62635 (other polymers)
PE		187	90%	168.6	IEC 62635
PMMA		6	0%	0.0	IEC 62635 (other polymers)
POM		230	0%	0.0	IEC 62635 (other polymers)
PP (various)		4981	90%	4482.6	IEC 62635
PS		512	83%	424.6	IEC 62635 (assumed as high impact polystyrene)
PU Foam - Insulation		2	0%	0.0	IEC 62635 (other polymers)
PVC		403	0%	0.0	IEC 62635 (other polymers)
Plastics (others)		268	0%	0.0	IEC 62635 (other polymers)
Adhesive		10.00	0%	0.0	no data available / unspecified
Bitumen		6089.00	0%	0.0	no data available / unspecified
Concrete and inerts		1262.80	0%	0.0	no data available / unspecified
Cotton and noise absorbers		941.18	0%	0.0	no data available / unspecified
Paper		205.52	0%	0.0	no data available / unspecified
Resins		120.00	0%	0.0	no data available / unspecified
Thermostat		10.00	0%	0.0	no data available / unspecified
Wood		2034.40	0%	0.0	no data available / unspecified
Others		59.36	0%	0.0	no data available / unspecified
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [g]				**32,374**	
Recyclability rate (R^* *cyc*) [%]		**67.2%**			

3.3.3 Recoverability rate index (in mass)

The calculation of the Recoverability rate index - R^*_{cov} - (in mass) [Ardente and Mathieux, 2012] is based on the identified typologies of product's parts, according to the set EoL scenario. The assumptions used for the DW case-study are explained in section 3.3.2.

Table 13 Recoverability rate index (scenario 1: shredding)

Product Details					
Product	**Mass (m) of the product [g]**				
Dishwasher (DW)	48,157				
Parts for selective treatment:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
External cables	Copper and plastic (PVC)	175	33%	57.8	High current cable from IEC 62635. Copper recycled; PVC landfilled
Parts for selective recycling:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
Parts difficult to process:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
Other parts (for material separation):					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
Aluminium		268.6	91%	244.4	IEC 62635
Brass		23.4	70%	16.4	IEC 62635 (other metals)
Chromium		71.3	70%	49.9	IEC 62635 (other metals)
Ferrous metals		27,266.0	94%	25630.0	IEC 62635 (steel general)
Pumps (copper)		656.0	70%	459.2	Johansson and Bjorklund 2011
Zinc		4.2	70%	2.9	IEC 62635 (other metals)
ABS		751.3	75%	563.4	IEC 62635
EPDM - rubber (external pipes)		524.0	5%	26.2	IEC 62635 (other polymers)
EPS		39.7	5%	2.0	IEC 62635 (other polymers)
PA		398.6	5%	19.9	IEC 62635
PBT polybutylene terephthalate		35.0	5%	1.8	IEC 62635 (other polymers)
PE		187.3	91%	170.5	IEC 62635
PMMA		5.8	5%	0.3	IEC 62635 (other polymers)
POM		229.9	5%	11.5	IEC 62635 (other polymers)
PP (various)		4,980.6	91%	4532.4	IEC 62635
PS		511.5	84%	429.7	IEC 62635 (assumed as high impact polystyrene)
PU Foam - Insulation		2.4	5%	0.1	IEC 62635 (other polymers)
PVC		403.2	5%	20.2	IEC 62635 (other polymers)
Plastics (others)		267.9	5%	13.4	IEC 62635 (other polymers)
Adhesive		10.0	0%	0.0	no data available / unspecified
Bitumen		6,089.0	0%	0.0	no data available / unspecified
Cables internal (copper and PVC)		175.0	0%	0.0	estimation (based on communication of recyclers)
Concrete and inerts		1,262.8	0%	0.0	no data available / unspecified
Cotton and noise absorbers		941.2	0%	0.0	no data available / unspecified
Paper		205.5	0%	0.0	no data available / unspecified
PCBs (various)		447.5	30%	134.3	no data available (assumed 50% of PCB selectively treated as in IEC 62635)
Resins		120.0	0%	0.0	no data available / unspecified
Thermostat		10.0	0%	0.0	no data available / unspecified
Wood		2,034.4	0%	0.0	no data available / unspecified
Others		59.4	0%	0.0	no data available / unspecified
Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [g]				**32,386**	
Recyclability rate ($R^{*}cyc$) [%]		**67.3%**			

Table 14 Recoverability rate index (scenario 2: combined treatment)

Product Details					
Product	**Mass (m) of the product [g]**				
Dishwasher (DW)	48,157				
Parts for selective treatment:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
External cables	Copper and plastic (PVC)	175	33%	57.8	High current cable from IEC 62635. Copper recycled; PVC landfilled
PCBs	Various materials	447.5	60%	268.5	IEC 62635 (PCBs intermediate)
Parts for selective recycling:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
Circulation Pump	Copper	560	95%	532.0	IEC 62635
Drain Pump	Copper	96	95%	91.2	IEC 62635
Cables internal (copper and PVC)		175.0	24%	42.0	IEC 62635 (low current cables assumed being extrated jointly with pumps)
Parts difficult to process:					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
External pipes	(EPDM - rubber)	524	5%	26.2	IEC 62635 (other polymers)
Other parts (for material separation):					
Parts and materials		**Mass ($m_{recov,i}$) [g]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [g]**	**References/details for the (RVR)**
Aluminium		268.6	91%	244.4	IEC 62635
Brass		23.4	70%	16.4	IEC 62635 (other metals)
Cromium		71.3	70%	49.9	IEC 62635 (other metals)
Ferrous metals		27,266.0	94%	25630.0	IEC 62635 (steel general)
Zinc		4.2	70%	2.9	IEC 62635 (other metals)
ABS		751.3	75%	563.4	IEC 62635
EPS		39.7	5%	2.0	IEC 62635 (other polymers)
PA		398.6	5%	19.9	IEC 62635
PBT polybutylene terephthalate		35.0	5%	1.8	IEC 62635 (other polymers)
PE		187.3	91%	170.5	IEC 62635
PMMA		5.8	5%	0.3	IEC 62635 (other polymers)
POM		229.9	5%	11.5	IEC 62635 (other polymers)
PP (various)		4,980.6	91%	4532.4	IEC 62635
PS		511.5	84%	429.7	IEC 62635 (assumed as high impact polystyrene)
PU Foam - Insulation		2.4	5%	0.1	IEC 62635 (other polymers)
PVC		403.2	5%	20.2	IEC 62635 (other polymers)
Plastics (others)		267.9	5%	13.4	IEC 62635 (other polymers)
Adhesive		10.0	0%	0.0	no data available / unspecified
Bitumen		6,089.0	0%	0.0	no data available / unspecified
Concrete and inerts		1,262.8	0%	0.0	no data available / unspecified
Cotton and noise absorbers		941.2	0%	0.0	no data available / unspecified
Paper		205.5	0%	0.0	no data available / unspecified
Resins		120.0	0%	0.0	no data available / unspecified
Thermostat		10.0	0%	0.0	no data available / unspecified
Wood		2,034.4	0%	0.0	no data available / unspecified
Others		59.4	0%	0.0	no data available / unspecified
			Sum of recyclable parts (Σ $m_{recyc,i}$ * RCR_i) [g]	**32,726**	
Recyclability rate ($R^{*}cyc$) [%]		**68.0%**			

Similarly to the analysis of Recyclability rate, the differences among the Recoverability rates for the two case-studies are not relevant in the two EoL scenarios (Table 13 and Table 14**Error! Reference ource not found.**). Also in this case, the majority of material losses[39] for the recoverability index are due to the landfill of bitumen and wood parts and to the partial recovery of ferrous metals.

3.4 Reusability / Recyclability / Recoverability benefits rate indexes

3.4.1 Reusability Benefit rate index

No reusable parts have been detected for the case-study DW (See section 3.3.1). The Reusability benefit rate of the DW is hence *0 %*.

3.4.2 Recyclability Benefit rate index

The Recyclability Benefit rate for the two EoL scenarios of Figure 6 was calculated according to the REAPro method. The assumptions considered for the calculation of the rates were:

- The impact of primary and recycled galvanized and stainless steels are assimilated to those of normal steel;
- The impacts of recycled plastics are roughly assumed 10% of primary ones[40];
- The Life-Cycle-Inventory data of recycled materials from various references [BUWAL, 1996; ecoinvent, 2007; PE, 2012];
- The benefits of the recycling of zinc, chromium and brass were not considered[41].

The recyclability benefit rate for all the considered impact categories are illustrated in Table 15, while the detailed calculations for the ADP_{el} impact category are presented in Table 15 and **Error! eference source not found.**.

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[39] Losses for each component are calculated as: $\text{Losses} = \frac{(1 - \text{Recovery rate})}{\text{Product mass}} \cdot 100$ [%].

[40] This assumption is based on data limited to PP plastics and relatively to the energy consumption impact category [Ardente et al., 2009],

[41] The contribution of these metals to the overall life cycle impacts has been assessed, however, not relevant (see section 2.3.3).

Table 15 Recyclability Benefit rate index: scenario 1 (shredding) and scenario 2 (combined treatment).

	Impact categories												
	Resource depletion el.	Resource depletion f.	Acidification	Climate change	Ozone Depletion	Terrestrial eutrophication	Freshwater eutrophication	Ionising radiation	Marine eutrophication	Respiratory effects	Photochemical oxidant	Ecotoxicity	Human toxicity
Indicator	Abiotic Depletion $ADP_{element}$	Abiotic Depletion ADP_{fossil}	Acidification Potential (AP)	Global Warming $GWP_{100years}$	Ozone Depletion ODP	Terrestrial Eutrophication	EUTREND fresh water	Human health effect	EUTREND marine	Particulate Matter Formation	LOTUS-EUROS	USEtox E.	USEtox H. T.
Unit	[kg $Sb_{Equiv.}$]	[MJ]	[kg $SO_{2\text{-}Equiv.}$]	[kg $CO_{2\text{-}Equiv.}$]	[kg $R11_{\text{-}Equiv.}$]	[m^2 UES]	[kg P eq]	[kg $U_{235\ eq}$]	[kg $N_{Equiv.}$]	[kg $PM_{10\ eq}$]	[kg NMVOC]	[PAF m^3.day]	[cases]
Sum of benefits	1.3E-03	4.7E+02	2.3E-01	6.5E+01	5.3E-06	2.2E+00	1.5E-03	1.0E+06	3.3E-02	6.5E-02	1.1E-01	7.1E-01	1.06E-09
Life cycle impacts	3.2E-03	1.7E+04	1.3E+01	1.8E+03	4.2E-04	8.4E+01	4.2E-03	4.6E+08	1.3E+00	3.0E+00	4.2E+00	2.3E+00	3.2E-08
	Recyclability Benefit Rate [%]												
Recyclability Benefit Rate (Scenario 1 - Shredding)	39.5%	2.7%	1.7%	3.5%	1.3%	2.6%	35.1%	0.2%	2.5%	2.2%	2.7%	31.1%	3.3%

	Impact categories												
	Resource depletion el.	Resource depletion f.	Acidification	Climate change	Ozone Depletion	Terrestrial eutrophication	Freshwater eutrophication	Ionising radiation	Marine eutrophication	Respiratory effects	Photochemical oxidant	Ecotoxicity	Human toxicity
Indicator	Abiotic Depletion $ADP_{element}$	Abiotic Depletion ADP_{fossil}	Acidification Potential (AP)	Global Warming $GWP_{100years}$	Ozone Depletion ODP	Terrestrial Eutrophication	EUTREND fresh water	Human health effect	EUTREND marine	Particulate Matter Formation	LOTUS-EUROS	USEtox E.	USEtox H. T.
Unit	[kg $Sb_{Equiv.}$]	[MJ]	[kg $SO_{2\text{-}Equiv.}$]	[kg $CO_{2\text{-}Equiv.}$]	[kg $R11_{\text{-}Equiv.}$]	[m^2 UES]	[kg P eq]	[kg $U_{235\ eq}$]	[kg $N_{Equiv.}$]	[kg $PM_{10\ eq}$]	[kg NMVOC]	[PAF m^3.day]	[cases]
Sum of benefits	2.5E-03	4.8E+02	3.2E-01	6.8E+01	5.6E-06	2.5E+00	1.5E-03	1.0E+06	3.7E-02	8.6E-02	1.3E-01	1.2E+00	1.06E-09
Life cycle impacts	3.2E-03	1.7E+04	1.3E+01	1.8E+03	4.2E-04	8.4E+01	4.2E-03	4.6E+08	1.3E+00	3.0E+00	4.2E+00	2.3E+00	3.2069E-08
	Recyclability Benefit Rate [%]												
Recyclability Benefit Rate (Scenario 2 - Combined treatment)	77.4%	2.8%	2.4%	3.7%	1.3%	3.0%	35.3%	0.2%	2.8%	2.9%	3.1%	54.1%	3.3%

Table 16 Recyclability Benefit rate (detail of ADP$_{el.}$): scenario 1 (shredding)

Product Details	
Product	**Mass (m) [kg]**
Dishwasher (DW)	48.2
Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential element (ADP$_{el}$)
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	Various (including Copper)	0.175	33%	1.9E-03	1.14E-09	2.19E-04	9.76E-05	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
PCB	Gold	1.70E-05	26%	5.8E+01	1.14E-09	2.22E-04	2.53E-04	primary / secondary gold (ecoinvent); (recycling rate from Meskers et al., 2009)
	Silver	7.16E-05	12%	1.4E+00	1.14E-09	3.80E-06	1.12E-05	primary / secondary silver (ecoinvent); disposal of metals from (ELCD)
	Palladium	8.95E-06	26%	6.6E-01	1.14E-09	1.47E-03	1.51E-06	primary / secondary palladium (ecoinvent); disposal of metals from (ELCD)
	Copper	0.125	60%	1.9E-03	1.14E-09	2.19E-04	1.27E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Pumps	Copper	0.656	70%	1.9E-03	1.14E-09	2.19E-04	7.76E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Various	Aluminium	0.27	91%	1.7E-05	1.14E-09	4.56E-05	-6.95E-06	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	Brass	0.02	70%	1.0E-03	1.14E-09	n.a.	n.a.	Brass primary from (ecoinvent);recycling of brass n.a. ; disposal of metals from (ELCD)
	Chromium	0.07	60%	4.0E-04	1.14E-09	n.a.	n.a.	Chromium primary from (ecoinvent);recycling of Chromium n.a. ; disposal of metals from (ELCD)
	Ferrous metals	27.27	94%	7.2E-08	1.14E-09	0E+00	1.86E-06	steel sheet (primary and secondary) from (BUWAL); disposal of metals from (ELCD)
	Zinc	0.004	70%	6.5E-04	1.14E-09	n.a.	n.a.	Zinc primary from (ecoinvent); recycling of zinc n.a.; disposal of metals from (ELCD)
	ABS	0.75	74%	1.5E-06	1.05E-08	1.50E-07	7.57E-07	primary ABS and plastic disposal from ELCD; no data about ABS recycling (assumed 10% of primary);
	PE	0.19	90%	2.7E-08	1.05E-08	2.73E-09	5.92E-09	primary PE-HD and plastic disposal from ELCD; no data about PE recycling (assumed 10% of primary);
	PP	4.98	90%	4.6E-07	1.05E-08	4.63E-08	1.92E-06	primary PP and plastic disposal from ELCD; no complete inventory data about PP recycling (assumed 10% of primary);
	PS	0.51	83%	4.0E-07	1.05E-08	4.02E-08	1.58E-07	Polystyrene production from (plasticeurope); disposal of plastics from (ELCD); no data inventory about PS recycling (assumed 10% of primary).

Life Cycle impacts of the product:

A. Impacts due to the production of materials (Σm * $E_{v,n}$) [unit]	3.1E-03	Details: (provided in the Life Cycle Assessment of the DW)
B. Impacts due to the manufacturing of the product (M_n) [unit]	8.5E-07	Details: (provided in the Life Cycle Assessment of the DW)
C. Impacts due to the use of the product (U_n) [unit]	1.4E-04	Details: (provided in the Life Cycle Assessment of the DW)
D. Impacts due to the disposal of materials (Σm * $E_{d,n}$) [unit]	1.8E-06	Details: (provided in the Life Cycle Assessment of the DW)
Sum of the impacts (A +B+C+D)	3.2E-03	kg Sb$_{eq.}$
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]	1.3E-03	kg Sb$_{eq.}$
Recyclability Benefit rate ($R'_{cyc,n}$) [%]	39.5%	

Table 17 Recyclability Benefit rate (detail of ADPel.): scenario 2 (combined treatment)

Product Details								
Product		**Mass (m) [kg]**						
Dishwasher (DW)		48.2						
Impact category for the calculation								
Impact category (n)		Abiotic Depletion Potential element (ADP_{el})						
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	Various (including Copper)	0.175	33%	1.9E-03	1.14E-09	2.19E-04	9.76E-05	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Internal Cables		0.175	24%	1.9E-03	1.14E-09	2.19E-04	7.10E-05	
PCB	Gold	1.70E-05	97%	5.8E+01	1.14E-09	2.22E-04	9.60E-04	primary / secondary gold (ecoinvent); (recycling rate from Meskers et al., 2009)
	Silver	7.16E-05	92%	1.4E+00	1.14E-09	3.80E-06	8.99E-05	primary / secondary silver (ecoinvent); disposal of metals from (ELCD)
	Palladium	8.95E-06	99%	6.6E-01	1.14E-09	1.47E-03	5.84E-06	primary / secondary palladium (ecoinvent); disposal of metals from (ELCD)
	Copper	0.12526	95%	1.9E-03	1.14E-09	2.19E-04	2.01E-04	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Pumps	Copper	0.656	95%	1.9E-03	1.14E-09	2.19E-04	1.05E-03	primary / secondary copper (ecoinvent); disposal of metals from (ELCD)
Various	Aluminium	0.27	91%	1.7E-05	1.14E-09	4.56E-05	-6.95E-06	primary aluminium and secondary aluminium (from scraps) from (ecoinvent); disposal of metals from (ELCD)
	Brass	0.02	70%	1.0E-03	1.14E-09	n.a.	n.a.	Brass primary from (ecoinvent);recycling of brass n.a. ; disposal of metals from (ELCD)
	Chromium	0.07	60%	4.0E-04	1.14E-09	n.a.	n.a.	Chromium primary from (ecoinvent);recycling of Chromium n.a. ; disposal of metals from (ELCD)
	Ferrous metals	27.27	94%	7.2E-08	1.14E-09	0E+00	1.86E-06	steel sheet (primary and secondary) from (BUWAL); impacts of primary and secondary galvanized and stainless steels assimilated to normal steel; disposal of metals from (ELCD)
	Zinc	0.004	70%	6.5E-04	1.05E-08	n.a.	n.a.	Zinc primary from (ecoinvent); recycling of zinc n.a.; disposal of metals from (ELCD)
	ABS	0.75	74%	1.5E-06	1.05E-08	1.50E-07	7.57E-07	primary ABS and plastic disposal from ELCD; no data about ABS recycling (assumed 10% of primary);
	PE	0.19	90%	2.7E-08	1.05E-08	2.73E-09	5.92E-09	primary PE-HD and plastic disposal from ELCD; no data about PE recycling (assumed 10% of primary);
	PP	4.98	90%	4.6E-07	1.05E-08	4.63E-08	1.92E-06	primary PP and plastic disposal from ELCD; no complete inventory data about PP recycling (assumed 10% of primary);
	PS	0.51	83%	4.0E-07	1.05E-08	4.02E-08	1.58E-07	Polystyrene production from (plasticeurope); disposal of plastics from (ELCD); no data inventory about PS recycling (assumed 10% of primary).
Life Cycle impacts of the product:								
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]		3.1E-03	Details: (provided in the Life Cycle Assessment of the DW)					
B. Impacts due to the manufacturing of the product (M_n) [unit]		8.5E-07	Details: (provided in the Life Cycle Assessment of the DW)					
C. Impacts due to the use of the product (U_n) [unit]		1.4E-04	Details: (provided in the Life Cycle Assessment of the DW)					
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]		1.8E-06	Details: (provided in the Life Cycle Assessment of the DW)					
Sum of the impacts (A +B+C+D)		3.20E-03	kg $Sb_{eq.}$					
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i) [unit]		2.48E-03	kg $Sb_{eq.}$					
Recyclability Benefit rate ($R'_{cyc,n}$) [%]		77.4%						

From the analysis of the scenarios, we can conclude that the recycling of product's components is relevant for the three impact categories: ADP_{el}, Ecotoxicity and Freshwater eutrophication. However, the different EoL treatments influence significantly only the ADP_{el} and the Ecotoxicity. This is due to the higher recycling rates of some precious metal (in PCBs) and copper (in PCB, pumps and wires) related to the EoL scenario 2 (combined manual dismantling plus shredding treatments).

3.4.3 Energy Recoverability Benefit rate index

The Energy Recoverability Benefit rate for the two EoL scenarios was calculated according to the REAPro method. Figure 6 gives the results of the ADP_{fossil} impact category[42]. The assumptions considered for the calculation of the rate were:

- The Low Heating Values of plastics were estimated from information in websites[43]
- The environmental impacts of electricity and heat are taken from the ELCD data based on EU-27 power mix and heat respectively;
- The environmental impact of the incineration of plastics (unspecified mixture) is taken from [ecoinvent, 2007];
- The energy recovery of PCB is assumed to be 90% for the epoxy resin support contained in the boards;
- The energy recovery of rubber pipes is assumed to be 5%[44], independently from being preliminary sorted or shredded at the EoL;
- Plastics (embodied into wirings) and wood (into panel boards) are assumed to be landfilled[45].

The energy recovery from the products after its EoL can allow to save less than 2% of the life cycle energy. Differences in the EoL scenario 1 and 2 (**Error! Reference source not found.** and Table 18 espectively) are not relevant.

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[42] The ADP_{fossil} is the impact category mostly influenced by the energy recovery of parts of the product.

[43] Data about EPDM, ABS, PA, PE, PMMA, PP, PS, PU and PVC refer to the GaBi Databases of life cycle inventory data (http://www.gabi-software.com/italy/databases/gabi-databases/ ; access November 2013); data about EPS and epoxy resins are derived from: http://seieditrice.com/manuale-di-costruzioni/files/2012/01/Potere-calorifico-al-kg.pdf (access November 2013).

[44] Estimation based on IEC/TR 62635 “other plastics”.

[45] No data available from IEC/TR 62635 nor from other references. It is assumed that these materials are collected together with the shredding residues and landfilled.

Table 18 Energy Recoverability Benefit rate (ADP$_{fossil.}$): scenario 1 (shredding)

Product Details	
Product	**Mass (m) of the product [kg]**
Dishwasher (DW)	48.2
Impact category for the calculation	
Impact category (n)	Abiotic Depletion Potential (fossil)
Unit of measure	MJ

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	0.04	50%	31	0.3	0.6	1.7	1.09	0.51	0.6	
Plastic parts (various)	ABS	0.75	75%	39	0.3	0.6	1.7	1.09	0.51	25.0	Low Heating Values of plastics from various references; impact of electricity (EU-27 power mix) and Heat (EU-27 heat) from ELCD; impact of incineration of plastics (generic mixture) from ecoinvent
	EPDM - rubber	0.52	5%	43	0.3	0.6	1.7	1.09	0.51	1.0	
	EPS	0.04	5%	40	0.3	0.6	1.7	1.09	0.51	0.1	
	PA	0.40	5%	32	0.3	0.6	1.7	1.09	0.51	0.5	
	PBT	0.04	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	
	PE	0.19	91%	43.5	0.3	0.6	1.7	1.09	0.51	8.5	
	PMMA	0.01	5%	25.1	0.3	0.6	1.7	1.09	0.51	0.0	
	POM	0.23	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	
	PP	4.98	91%	43.5	0.3	0.6	1.7	1.09	0.51	225.4	
	PS	0.51	84%	39.6	0.3	0.6	1.7	1.09	0.51	19.4	
	PU Foam	0.00	5%	25.5	0.3	0.6	1.7	1.09	0.51	0.0	
	PVC	0.40	5%	18	0.3	0.6	1.7	1.09	0.51	0.2	
	Plastics (others)	0.27	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	

Life Cycle impacts of the product:		
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]	1.1E+03	Details in the text
B. Impacts due to the manufacturing of the product (M_n) [unit]	1.4E+02	Details in the text
C. Impacts due to the use of the product (U_n) [unit]	1.6E+04	Details in the text
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]	2.5E+01	Details in the text
Sum of the impacts (A +B+C+D)	1.7E+04	MJ
Sum of benefits due to energy recoverable	2.81E+02	MJ
Energy Recoverability Benefit rate ($R'_{cov,n}$) [%]	1.6%	

Table 19 Energy Recoverability Benefit rate (ADP fossil): scenario 2 (combined treatment)

Product Details										
Product		**Mass (m) of the product [kg]**								
Dishwasher (DW)		48.2								
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	0.04	90%	31	0.3	0.6	1.7	1.09	0.51	1.2	Low Heating Values of plastics from various references; impact of electricity (EU-27 power mix) and Heat (EU-27 heat) from ELCD; impact of incineration of plastics (generic mixture) from ecoinvent
External pipes	(EPDM - rubber)	0.52	5%	43	0.3	0.6	1.7	1.09	0.51	1.0	
Plastic parts (various)	ABS	0.75	75%	39	0.3	0.6	1.7	1.09	0.51	25.0	
	EPS	0.04	5%	40	0.3	0.6	1.7	1.09	0.51	0.1	
	PA	0.40	5%	32	0.3	0.6	1.7	1.09	0.51	0.5	
	PBT	0.04	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	
	PE	0.19	91%	43.5	0.3	0.6	1.7	1.09	0.51	8.5	
	PMMA	0.01	5%	25.1	0.3	0.6	1.7	1.09	0.51	0.0	
	POM	0.23	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	
	PP	4.98	91%	43.5	0.3	0.6	1.7	1.09	0.51	225.4	
	PS	0.51	84%	39.6	0.3	0.6	1.7	1.09	0.51	19.4	
	PU Foam -	0.00	5%	25.5	0.3	0.6	1.7	1.09	0.51	0.0	
	PVC	0.40	5%	18	0.3	0.6	1.7	1.09	0.51	0.2	
	Plastics (others)	0.27	5%	n.a.	0.3	0.6	1.7	1.09	0.51	-	
Life Cycle impacts of the product:										
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]			1.1E+03	Details in the text						
B. Impacts due to the manufacturing of the product (M_n) [unit]			1.4E+02	Details in the text						
C. Impacts due to the use of the product (U_n) [unit]			1.6E+04	Details in the text						
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]			2.5E+01	Details in the text						
Sum of the impacts (A +B+C+D)			1.7E+04	MJ						
Sum of benefits due to energy recoverable			2.81E+02	MJ						
Energy Recoverability Benefit rate (*$R'_{cov,n}$*) [%]			1.6%							

3.5 Recycled content of DW

3.5.1 Recycled content index (in mass)

The Recycled content index accounts for the percentage of recycled materials used to manufacture a product [Ardente and Mathieux, 2012]. The aim of the analysis is to evaluate the relevance of using recycled materials and compared it with the overall mass of the product.

The average content of recycled materials in the case-study DW is unknown. Following recommendations of [Ardente and Mathieux, 2012b], the analysis focuses on those materials having a lower economic value and higher downcycling when recycled, i.e. polymers. The BoM presented in Table 1 shows that the two most relevant plastics in DWs (in mass) are acrylonitrile-butadiene-styrene (ABS) and Polypropylene (PP). Table 20 shows the Recycled content of the DW assuming that the recycled content of ABS and PP varies from 0% to 50%. The results show that the percentage of the recycled content in the product is generally is up to 6%, thus not relevant, even when the 50% of these two plastics is recycled.

Table 20 **Recycled content index**

Recycled content (in mass) [%]						
Materials with a recycled content	Percentage of material recycled					
	0	10	20	30	40	50
ABS	0	0.2	0.3	0.5	0.6	0.8
PP	0	1.0	2.1	3.1	4.1	5.2
PP and ABS	0	1.2	2.4	3.6	4.8	6.0

3.5.2 Recycled content benefit index

The calculation of the Recycled content benefits requires information concerning the life cycle inventory of recycled plastics. However, in the literature survey there is a general lack of information on such topic [Ardente and Mathieux, 2012b]. As result, the analysis was limited to the most relevant plastic contained in the product (PP), and only to the energy consumption impact category (ADP_{fossil}[46]).

Ardente et al. (2009) demonstrate that the life cycle energy consumption of PP ranges from 80 to 10 MJ/kg for a recycled content that varies from 10% to 90%. It is further assumed linear trend on the variation of the energy consumption with the recycled content of PP.

Table 21 presents the Recycled content benefit of the DW. Even when using high percentages of recycled PP (e.g. 50%) in several parts of DW, the environmental benefits only amount up to 1% of the life cycle energy consumption. This is mainly due to the dominant influence of the use phase in the life cycle energy consumption of a DW. In general, it can be concluded that the use of recycled plastics parts for the manufacturing of a DW has a low relevance in its environmental impact from a life cycle perspective.

Table 21 **Recycled content benefit index [%] of the DW with different recycled content values of PP parts**

Recycled content benefit of the DW						
	Recycled content of PP parts					
	0%	10%	20%	30%	40%	50%
ADP_{fossil} of PP [MJ/kg]	80.0	72.2	64.4	56.7	48.9	41.1
ADP_{fossil} of PP parts in DW [MJ]	398.4	359.7	321.0	282.2	243.5	204.8
Benefits of using recycled PP [MJ]	0.0	38.7	77.5	116.2	155.0	193.7
ADP_{fossil} of DW [GJ]	17.21					
Recycled content benefit [%]	0.0%	0.2%	0.5%	0.7%	0.9%	1.1%

3.6 Use of hazardous substances

This assessment aims to identify the components of the DW that need to be managed with special care in order to minimize the risks of diffusion/loss of hazardous substances in the environment [Ardente et Mathieux, 2012b]. The assessment is based on the following steps:

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[46] This impact category accounts (in primary MJ) for the life cycle consumption of fossil fuel to produce the materials. It is also sometimes referred with other names, as Global Energy Requirement – GER, or Cumulative Energy Demand – CED. The ADP_{fossil} generally represents one of the most relevant impact categories for plastics [Ardente and Mathieux, 2012].

- ‘Step 1 – substances considered’. The analysis was restricted to substances regulated by the RoHS directive.

- ‘Step 2 - identification of components embodying the substances’. The identification of components was performed based on information collected at recycling facilities and data available from the scientific literature, as a detailed BoM of the hazardous substances contained in a DW was not available (especially the content of substances in the electronic components and plastics). The components potentially relevant for the analysis are:
    - PCBs and capacitors. For their content in mercury and cadmium (average content are given in Table 4), and the content of polychlorobiphenyl.
    - LCD screens (if included[47]). 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 scenarios, the treatments are:
    - PCBs larger of 10 cm^2 are preliminarily 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 remain in the residues to be incinerated / landfilled;
    - LCD, smaller than 100 cm^2, if present, are manually disassembled. No evidences about further treatments for the separation of hazardous substances potentially embedded are found.

- ‘Step 4 - identification of key components’. According to the previous steps, it is assessed that PCB larger than 10cm^2 represent a critical component for the content of hazardous substances, while the treatment of LCD screens (when included) could represent a hot-spot of the treatment of DW.

3.7 Durability of the DW

The product lifetime considered in the preparatory study on Ecodesign requirements for DW was 12.5 years. However according to ISIS (2007), the lifetime is estimated to vary from 10 to 17 years; furthermore, about 18% of the surveyed DWs are being already serviced or repaired in order to increase their lifetime [ISIS, 2007].

Similar average lifetimes are also considered by other authors (VHK (2005) estimated from 12 to 15 years, Johansson and Luttropp (2009) 10 to 15 years, and Zhifeng et al. (2012) 12 years)..

The durability of DW was calculated according to the REAPro method, based on the “Simplified Durability index D'_n” for some “n” impact categories [Ardente and Mathieux, 2012]. The assumptions introduced were:

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[47] Even if the considered case-study does not include LCD, according to contacted recyclers, it is expected in the next future a progressive growing number of devices embodying such parts, especially those belonging to the medium-high price segment.

- The DW of section 2.2 is assumed as case-study product "A" for the analysis. The function considered for the analysis if the cleaning of dishes for a fixed time frame: T" of 12 [years];
- The extension of the operative time "X" is assumed to range from 1 to 4 years (overall lifetime ranging from 12 to 16 years);
- The index "D'_n" is here calculated for the impact categories of section 2.3.3.
- The energy consumption "U_n" during the use phase of the case-study product[48] is: 233 kWh/year[49];
- The energy consumption of the substituting product "B" during the use stage is assumed to range from 100% to 85% of that of the case-study of DW[50]. It assumed that water consumptions do not change;
- The life-cycle impact for production "P_n" of the case-study product is calculated as the sum of impacts of the manufacturing and the production of materials (see section 2.3.2 for details);
- The life-cycle impacts "R_n" for the additional treatments (i.e. repairing) for extending the operating time of the DW are not available. As result, we perform a scenario analysis ("low repairing scenario - LRS" and "high repairing scenario - HRS")[51], where "R_n" was set as follows[52]:
    - From 5% to 20 % for the impact categories: ADP_{el} and ecotoxicity;
    - From 5% to 10% for the impact category: freshwater eutrophication;
    - From 0.5% to 1% for all the other impact categories.

Table 22 summarizes the main assumption for the calculation of the Simplified Durability index D'_n; and Table 23 illustrates the life cycle impacts of the DW under study used as input for the calculations. Details of the Simplified Durability index for all the considered impact categories are illustrated in Annex I. The main conclusions of the analysis are:

- The prolongation of the lifetime of a DW is always beneficial even when the use of a DW with the same energy efficiency is postponed.
- The extension of the lifetime of a DW reduces up to about 30% impact categories as ADP_{el}, freshwater eutrophication and ecotoxicity (i.e. those impact categories more influenced by the manufacturing phase).

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[48] Assumptions as in Table 5.

[49] This consumption is corresponding to "A++" dishwasher according to the [EC, 2010].

[50] It is noticed that the passage from a class of energy to the next more energy efficient allow the saving of about 10%-12% of energy during use.

[51] The "low repairing scenario" can be considered representative of a minor intervention for the prolongation of the useful life (corresponding, for example to the substitution of a low impact parts, as the pipes or seals). The "high repairing scenario" is instead representative of a major intervention of repairing (e.g. substitution of a relevant component as a pump or a Printed Circuit Board).

[52] These percentages have been set according to the relevance of the production phase to each impact category. The ranges have been set sufficiently large in order to consider the uncertainties of the estimations.

- For the same impact categories, differences between the "low-repair scenario - LRS" and the "high-repair scenario - HRS" are relevant. An extension of the lifetime larger than 2 years in the HRS (i.e. the substitution of some relevant parts) reduces the environmental impact on the ADP_{el}. For example, extending the lifetime of a DW (in the LRS scenario) by 4 years, postponing the use of a 15% more energy efficient device, can potentially grant the saving of 27% of the ADP_{el} impact. For a HRS scenario, the potential benefits amount to 13%.
- Variations among the two scenarios (LRS and HRS) for the other impact categories are not relevant.
- . For example (Figure 8), extending the lifetime of a DW by 4 years, thus postponing the use of 5% more energy efficient device, would save 1.3% of the GWP impact.

Table 22 Assumptions for the calculation of the Simplified Durability index D'_n

Case study product (A)		
Operating time "T"	12	[years]
Energy consumption (during the use)	233	[kWh/year]
Total energy consumption for use	2.8	[MWh]
Extension of life time "X"	From 1 to 4 [years]	
Replacement product (B)		
Energy consumption (δ) of product "B" compared to "A"	from 85% to 100%	

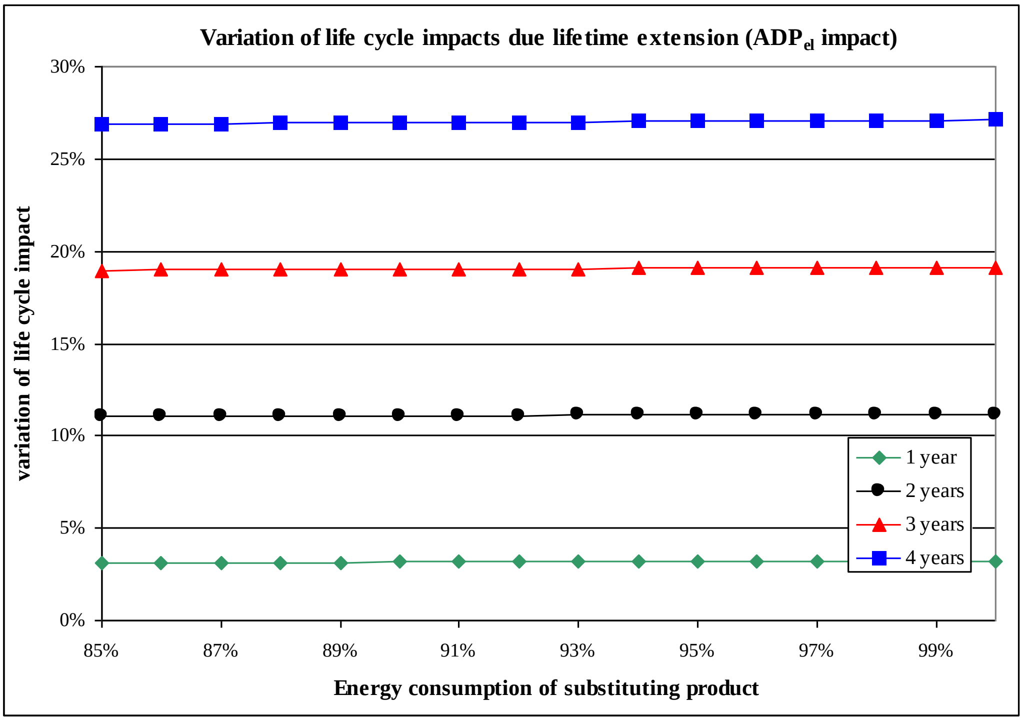

Figure 7 Analysis of Simplified Durability Index (ADP_{el} – Low-repair scenario)

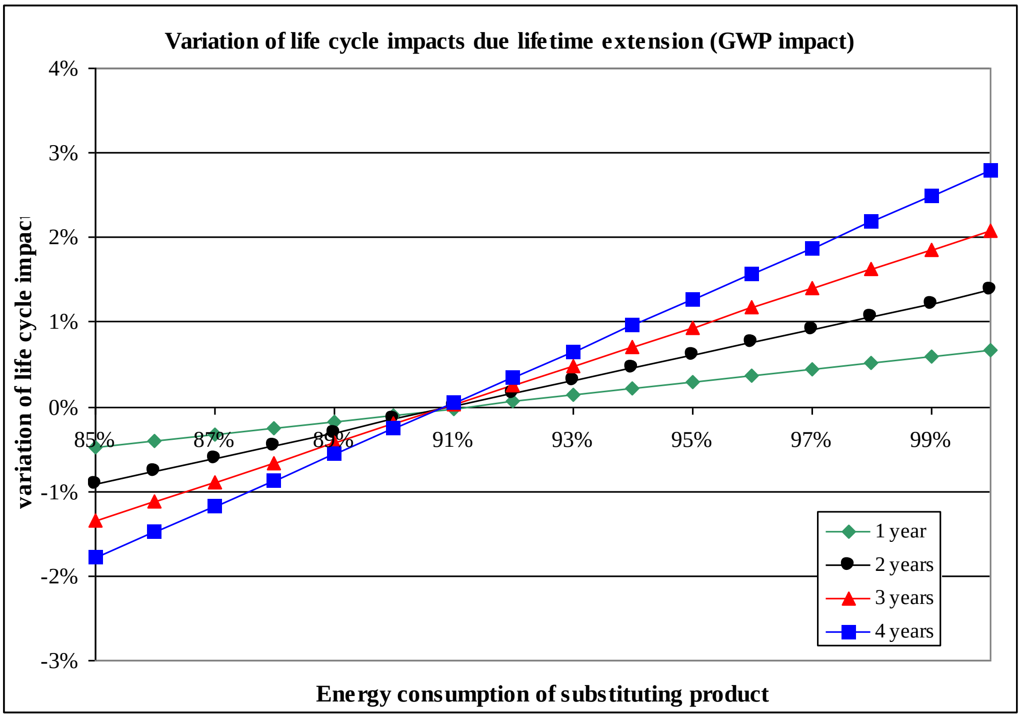

Figure 8 Analysis of Simplified Durability Index (GWP – Low-repair scenario)

Table 23 Life cycle impacts for the calculation of the Simplified Durability index D'_n

		Life cycle input data for Durability Analysis of Dishwasher												
		Abiotic Depletion (ADP_{el})	Abiotic Depletion (ADP_{fossil})	Acidification Potential (AP)	Global Warming Potential (GWP)	Ozone Layer Depletion Potential (ODP)	Terrestrial eutrophication	Freshwater eutrophication	Ionising radiation	Marine eutrophication	Particulate matter formation	Photochemical oxidant formation	Ecotoxicity	Human toxicity
		[kg $Sb_{Eq.}$]	[MJ]	[kg $SO_{2\text{-}Eq.}$]	[kg $CO_{2\text{-}Eq.}$]	[kg $R11_{\text{-}Eq.}$]	[m^2 UES]	[kg P_{eq}]	[kg $U_{235\ eq}$]	[kg $N_{Equiv.}$]	[kg $PM_{10\ eq}$]	[kg NMVOC]	[PAF m^3.day]	[cases]
P_n		3.1E-03	1.2E+03	6.8E-01	1.5E+02	1.4E-05	6.8E+00	1.9E-03	4.8E+06	1.0E-01	2.3E-01	3.3E-01	1.8E+00	2.1E-09
D_n		1.8E-06	2.5E+01	8.3E-03	6.2E+00	8.1E-08	2.1E-01	1.4E-03	9.5E+04	4.7E-03	2.7E-03	1.0E-02	3.0E-03	1.1E-10
R_n	*LRS*	1.5E-04	6.2E+00	3.4E-03	7.5E-01	6.9E-08	3.4E-02	9.4E-05	2.4E+04	5.1E-04	1.2E-03	1.6E-03	8.8E-02	1.1E-11
	HRS	6.1E-04	1.2E+01	6.8E-03	1.5E+00	1.4E-07	6.8E-02	1.9E-04	4.8E+04	1.0E-03	2.3E-03	3.3E-03	3.5E-01	2.1E-11
		Abiotic Depletion (ADP_{el})	Abiotic Depletion (ADP_{fossil})	Acidification Potential (AP)	Global Warming Potential (GWP)	Ozone Layer Depletion Potential (ODP)	Terrestrial eutrophication	Freshwater eutrophication	Ionising radiation	Marine eutrophication	Particulate matter formation	Photochemical oxidant formation	Ecotoxicity	Human toxicity
		[kg $Sb_{Eq.}$/year]	[MJ/year]	[kg $SO_{2\text{-}Eq.}$/year]	[kg $CO_{2\text{-}Eq.}$/year]	[kg $R11_{\text{-}Eq.}$/year]	[m^2 UES/year]	[kg P_{eq}/year]	[kg $U_{235\ eq}$/year]	[kg $N_{Eq.}$/year]	[kg $PM_{10\ eq}$/year]	[kg NMVOC/year]	[PAF m^3.day/year]	[cases/year]
U_n		1.2E-05	1.3E+03	1.1E+00	1.4E+02	3.3E-05	6.4E+00	7.8E-05	3.8E+07	9.9E-02	2.3E-01	3.2E-01	4.4E-02	2.5E-09

Based on a literature review, the components most frequently subjected to failures are:

- Motor, circulation and drain pumps. Motor failure is often caused by the use of low quality rolling element bearing instead of plain bearings. Motors should be designed to be easily separated from the pump to change the damaged part whilst maintaining the operational part. Pumps can break down due to the low quality joints and bedding. Water leakage causes the oxidation of the plain bearings of the motor, flooding and /or the activation of the security sensor. Using better quality seals can avoid leakages [Rreuse, 2013].
- Piping equipment (hoses, valves, filters, etc). Hoses can be damaged due to their proximity to the resistor and the low quality of the materials of the tubes [Rreuse, 2013].
- Electric and electronics (PCB, timers, heating system, switches, thermostat, etc). Electronic board failure is often caused by the lack of current and voltage protectors. Mechanical timers can breakdown due to the wearing out of cams and contacts. Electronic timers can fail due to the breakdown due to electronic component. Standardisation of these parts would ease their replacement and repair [Rreuse, 2013].
- Structural and interior parts (mainly related to door's parts, spray arms, seals and racks). Using better quality materials can avoid breakages.

No standards were identified for the assessment of the durability and lifetime of DWs or some of its key components[53].

3.8 Hot-spots for resource efficiency of DW

Based on the analysis of the previous sections, Table 24 presents some hot-spots[54] regarding resource efficiency of DW.

Table 24 Hot-spots for resource efficiency of DW

Criteria	Hot-spots
Reusability / recyclability / recoverability (in mass)	-
Reusability / recyclability / recoverability (environmentally based)	PCB, pumps
Recycled content (in mass)	-
Recycled content (environmentally based)	-
Use of hazardous substances	PCB; LCD screens
Durability	- motor (circulation and drain pumps), - piping (hoses, valves, filters, etc) - electric and electronics - structural and interior parts

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[53] However, according to a survey in the websites, several manufacturers claim to perform durability tests on sample of devices before put them in the market. Tests are generally based on intensive use under pre-set conditions, in order to simulate the total number of washing cycles during lifetime. These manufacturers' procedures could be potentially translated into standardized procedures.

[54] Hot-spots: materials/ components and processes which are critical for resource efficiency during the EoL treatments of DW according to considered criteria.

4. Identification and assessment of potential measures for resource efficiency of DW

4.1 Introduction

Based on the outcomes of the previous sections, the present chapter illustrates some potential measures for resource efficiency of DW. Measures are preliminary discussed and subsequently potential environmental benefits related to their application are estimated.

4.2 Analysis of potential Ecodesign measures for DW

The analysis of the outcomes of the REAPro method (Table 24) leads to the following conclusions:

- PCB and pumps are relevant both for the environmentally based RRR and durability. The access and extraction of these components for recycling and/or for substitution could generate environmentally relevant life cycle benefits;
- Several other components, potentially affected by common failures, are relevant for the durability. Accessibility to these components and availability of spare parts would facilitate the extension of the lifetime of the DW.
- LCD screens, when included, represent a problem during EoL pre-treatments due to the potential risk of contamination of recyclable fractions with some hazardous substances.

The next subsections propose a brief list of ecodesign measures that would help improve the EoL of DW.

4.2.1 Extraction of PCB, LCD screen and pumps

a) Identification of the requirement

As previously discussed, PCBs, pumps and LCD screens contained in DW concentrate the greatest amount of scarce and critical metals which if recovered and recycled can provide additional benefits from a resource efficiency perspective. The EoL treatments of these parts will significantly affect the results of the environmental impact of dishwashers.

The extraction of these components before shredding can help obtaining higher recovery amounts of copper and some precious metals as gold, silver and palladium, and potentially also indium (from LCDs). Furthermore, separating these components before shredding allow avoiding the contamination of other recyclable fraction by the potential hazardous substances they contain.

As highlighted by existing literature for this product group (See Section 1), and also as shown for other product groups (see e.g. [Ardente et al, 2014] for electronic displays), the measurement of time for dismantling of some components can be seen as an appropriate proxy to assess the ability of a product to be dismantled. Therefore, an example of potential product's requirements for the extraction of key components is following presented.

Potential Requirement: Design for Extraction of the key components of the dishwashers

The time for the extraction[55] of Printed Circuit Boards (PCB) assembly larger than 10 cm^2, LCD screens and pumps (circulation pump and drain pump) in the dishwasher shall not exceed 300[56] seconds, performed by professional worker.

Verification:

The measurement and verification of the time for extraction shall be made using a standardized, accurate and reproducible measurement procedure, which takes into account the generally recognised state of the art measurement methods.

The implementation of this type of requirement in the context of the Ecodesign Directive would require the development of appropriate standardized method to verify the requirement.

b) Assessment of potential benefits of the requirement at the case-study level

The improvement of the design for the extraction of PCB, pumps and LCD screens contained in DW would help split them from the other waste flows and treat them separately before shredding. Such separation step would provide the additional amount of materials calculated in Table 25[57]. These amounts are estimated taking into account the different recycling rates for each metal in different EoL scenarios (i.e. shredding and combined scenarios previously discussed in chapter 3). Table 26 shows the life cycle benefits of obtaining those additional amounts of recycled materials.

Table 25 Additional amount of metals potentially recovered from a DW

Material	Average content (g)	A. Recovery yields after mechanical shredding and sorting		B. Recovery yields after manual extraction		Difference of recovery yields (B - A)
Copper (pumps)	656.00	70%	459.20	95%	623.20	164.00
External cables [1]	175.00	33%	57.75	33%	57.75	0.00
Internal cables [2]	175.00	0%	0.00	24%	42.00	42.00
Copper (in PCBs)	125.30	60%	75.18	95%	119.04	43.86
Total copper	**1131.30**		**592.13**		**841.99**	**249.9**
Silver (in PCBs)	**0.072**	12%	**0.009**	95%	**0.068**	**0.060**
Gold (in PCBs)	**0.017**	26%	**0.004**	97%	**0.016**	**0.012**
Palladium (in PCBs)	**0.009**	26%	**0.002**	99%	**0.009**	**0.007**

[1] External cables contain 57.8 g of copper, [2] Internal cables contain 42 g of copper

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[55] The extraction is here intended referring to both the manual disassembly (eventually assisted by tools and machines) and the use of automatic systems for the dismantling of the component.

[56] This threshold value has been estimated on the basis of values reported by [Johansson and Luttropp, 2009]. As illustrated in section 1.2.3, authors demonstrated that typically 5 minutes of work gained about 75% of the copper. With some design efforts dishwashers could be optimized for disassembly and copper contained could be fully removed in approximately 2 minutes. Therefore a threshold of 4 minutes has been here set in order to allow the recovery the pumps PCB and LCD screen (when included).

[57] It is assumed that the improved extractability of key components would also improve the extraction of internal cables, which are connected to them. Recovery of external cables will be, instead, not affected.

Table 26 Life cycle benefits related to the improved extraction of key components of DW

Benefits of improving extraction of key components of DW		
Abiotic Depletion (ADP_{el})	[kg $Sb_{Equiv.}$]	1.2E-03
Abiotic Depletion (ADP_{fossil})	[MJ]	9.0E+00
Acidification Potential (AP)	[kg $SO_{2\text{-}Equiv.}$]	2.0E-01
Global Warming Potential (GWP)	[kg $CO_{2\text{-}Equiv.}$]	7.4E-01
Ozone Layer Depletion Potential (ODP)	[kg $R11_{\text{-}Equiv.}$]	7.3E-08
Terrestrial eutrophication	[m^2 UES]	5.7E-01
Freshwater eutrophication	[kg P eq]	2.2E-05
Ionising radiation	[kg $U_{235\ eq}$]	5.8E+04
Marine eutrophication	[kg $N_{Equiv.}$]	6.2E-03
Particulate matter formation	[kg $PM_{10\ eq}$]	4.8E-02
Photochemical oxidant formation	[kg NMVOC]	2.7E-02
Ecotoxicity	[PAF m^3.day]	8.3E-01
Human toxicity	[cases]	1.2E-10

Economic gains for the additional recycling of metals are estimated in Table 27, assuming that the cost for recycling copper from pumps and cables amounts to about 10% of the current price for primary copper, and that costs for recycling copper, gold, silver and palladium from PCBs range from 20% to 30% of the price for primary metals[58].

Table 27 Potential economic gain related to additional yields of copper, silver, gold and palladium in DWs

Metal	Price of metal[59]	Additional materials recycled	Economic gain
	[€/g]	[g/DW]	[€/DW]
Copper [a]	0.0054	206.00	1.00
Copper [b]	0.0054	43.86	0.17-0.19
Silver	0.51	0.060	0.02
Gold	30.98	0.012	0.26-0.30
Palladium	16.58	0.007	0.08-0.09
Total			**1.53-1.60**

[a] Copper contained in pumps and external cables, [b] Copper contained in PCBs.

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[58] The Institute of scrap recycling industries Inc (ISRI) identifies 53 types of copper and copper alloy scrap [Goonan, T. 2010]. The recycling of copper from scrap depends on its content, and thus its final price. The cost of recycling copper from pumps is calculated assuming that the cost of its recycling is about 10% of its price, as copper contained in pumps and cables remains low contaminated and with higher quality thus it's easier to recycle. Such copper is usually remelted to be reused in high copper grade products [CDA, 1994]. The additional economic gains to recover the metals in PCBs are calculated assuming that the cost for recycling each metal ranges from 20% to 30% of its price. Copper contained in PCBs is mixed up with other metals and impurities, and therefore it is necessary to re-refine it back to pure copper [CDA, 1994].

[59] Values of the prices of copper, silver, gold and palladium are taken from Infomine 2013 (http://www.infomine.com) and metalprices 2013 (www.metalprices.com)

c) Assessment of potential benefits of the requirement at the product group level

The overall potential benefits that the proposed measure can have in the market can be estimated by considering the total number of DWs that would benefits of such requirements.

In particular, based on the EoL scenarios defined in section 3.2, it is assumed that this requirement would affect DW undergoing dismantling, pre-shredding and shredding, while not affecting the DW treated only by shredding. It is assumed that about 50% of the European waste DW could potentially benefits of this requirement. This corresponds to about 4.1 millions of DW (considering about 8.26[60] [million/year] of DW sold yearly in the EU27).

Table 27 illustrates the environmental benefits related to an improved extraction of PCB, LCD and pumps from DW before shredding. These results have been normalized to the life cycle impacts of the product group (Table 27 - column B). The potential environmental benefits during the life cycle of the product group range from 0.2% (for the human toxicity impact category) to 19.4% (for the abiotic depletion potential).

In 2010 the EU already enforced some ecodesign measures for the DW product group [EC, 2010]. It is estimated that these measures will produce an energy saving of 2 TWh/year of electricity[61]. The related environmental life cycle benefits associated to this energy saving have been estimated in Table 28 (column C)[62]. The environmental benefits of the proposed measure for resource efficiency of DW have been compared to benefits from these Ecodesign implementing measures (Table 27 – column C). It is observed that benefits related to the extraction of key components (PCB, LCD and pumps) are much higher for the Abiotic depletion element (60 times higher) and ecotoxicity (10 times higher) impact categories. Relevant benefits relate also to the Freshwater eutrophication impact, Acidification potential and particulate matter formation.

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[60] Annual dishwashers sold in 2012. “EUROSTAT - Statistics on the production of manufactured goods”. http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/tables_excel, last updated February 2013).

[61] http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/files/brochure_ecodesign_en.pdf

[62] Overall environmental benefits related to the 2 TWh energy saving have been calculated assuming the average EU27 power grid mix at the consumer (life cycle inventory data from [ELCD, 2010])

Table 28 Life cycle benefits for the improved extraction of key components (at product group level)

	A. Benefits of improving extraction of key components of DW		B. Life Cycle impacts of the product group	Fraction (A/B) [%]	C. Benefits of implementing measures currently in force	Fraction (A/C) [%]
Abiotic Depletion (ADP_{el})	[10^3 kg $Sb_{Equiv.}$]	5.1E+00	2.6E+01	19.4%	8.0E-02	6429.8%
Abiotic Depletion (ADP_{fossil})	[TJ]	3.7E+01	1.4E+05	0.0%	1.1E+04	0.3%
Acidification Potential (AP)	[10^3 kg $SO_{2\text{-}Equiv.}$]	8.3E+02	1.1E+05	0.8%	9.1E+03	9.2%
Global Warming Potential (GWP)	[10^3 kg $CO_{2\text{-}Equiv.}$]	3.1E+03	1.5E+07	0.0%	1.2E+06	0.3%
Ozone Layer Depletion Potential (ODP)	[10^3 kg $R11_{\text{-}Equiv.}$]	3.0E-04	3.4E+00	0.0%	2.9E-01	0.1%
Terrestrial eutrophication	[10^3 m^2 UES]	2.3E+03	6.9E+05	0.3%	5.4E+04	4.3%
Freshwater eutrophication	[10^3 kg P eq]	9.0E-02	3.4E+01	0.3%	6.5E-01	13.8%
Ionising radiation	[10^3 kg $U_{235\ eq}$]	2.4E+08	3.8E+12	0.0%	3.2E+11	0.1%
Marine eutrophication	[10^3 kg $N_{Equiv.}$]	2.5E+01	1.1E+04	0.2%	8.3E+02	3.1%
Particulate matter formation	[10^3 kg $PM_{10\ eq}$]	2.0E+02	2.5E+04	0.8%	2.0E+03	10.1%
Photochemical oxidant formation	[10^3 kg NMVOC]	1.1E+02	3.5E+04	0.3%	2.7E+03	4.1%
Ecotoxicity	[10^3 PAF m^3.day]	3.4E+03	1.9E+04	18.2%	3.7E+02	937.5%
Human toxicity	[10^3 cases]	5.1E-07	2.6E-04	0.2%	2.1E-05	2.4%

Table 29 shows the additional amounts of recycled materials that can be potentially obtained due to the implementation of the requirement on extractability of key components. The implementation of the previous proposed requirement would allow the additional[63] yearly recovery of about 1.031 tonnes of copper, 247 kg of silver, 50 kg of gold and 27 kg of palladium.

Values in Table 29 have been also normalized to the amounts of materials used for DW and the overall amount of materials used within EU27[64]. For example, the additional amount of recycled metals corresponds to about of 11% of copper, 41% of silver, 35% of gold and 36% of palladium contained in waste DW.

Table 29 Amount of materials recycled from DW and their share in the product group and in the EU27

	A. Additional materials recycled [tonne / year]	B. Materials used in the product group [tonne/year]	Fraction (A/B) [%]	C. Materials used in the EU27 [tonne/year]	Fraction (A/C) [%]
Copper	1,031	9,344	11.0	3,525,910	0.029
Gold	0.05	0.14	35.5	130	0.038
Silver	0.247	0.59	41.5	12,050	0.002
Palladium	0.027	0.07	36.5	720	0.004

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[63] Additional recovery compared to the EoL scenario when the DW is directly shredded without manual pre-treatments.

[64] Values from [Ardente et Mathieux, 2012b]

The recovered amounts in Table 29 are also used to calculate the related potential economic gain. This is ranging from 6.3 to 6.6 million € (based on price figure of Table 27).

Considering an overall labour cost for a dismantlers of about 150 €/day [Salhofer et al. 2011], it is also estimated that the extraction of key components in DW is economically viable when *the time for extraction is, on average, below 300 seconds*. This threshold is in line with the proposed potential requirement.

4.2.2 Extending the lifetime of the DW

a) Identification of the requirements

The previous chapters demonstrated the potential environmental convenience into extending the operating time of DWs. This extension could be achieved by means of some general strategies, including [Ardente et al., 2012]:

- Non-destructive disassemblability[65] of key components for durability and their reparability and/or possibility of substitution (including the availability of spare parts). The design of components as trays and accessories should be done to allow as much as possible the interchange across different machines from the same and different manufacturers. The cost of spare part shall be comparable to the cost of the production of a new part.
- Extended warranties.
- Provision of information. Manufacturer could guarantee the accessibility to special hardware and software and the related specific training required to diagnose the faults to non-official after sales service providers.

Examples of potential product's requirements are following presented.

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[65] Non-destructive disassembly implies the ability to disassembly the component without damaging it and the other product's parts. This condition is more restrictive than the simple "disassemblability" (as discussed, for example for the requirements for extraction of key parts, which do not imply the conservation of the integrity of the components and connecting parts.

Potential Requirement: Design for substitutability of key spare parts of the DW

The manufacturer should design functional key components of the DW (including pumps, printed circuit boards, heating system, thermostat, valves, filters, hoses, spray arms, door panel, seals and racks)[66] in a way that:

- Each part can be reversible disassembled[67] in less than 20 minutes[68] for replacement and/or repairing
- Spare parts of the key component are available for purchasing.

Detailed information on the disassembly and repair of key components shall be provided in the user manuals and manufacturer's website. Manufacturers shall also provide a list of suggestions and good practises to prolong the lifetime of the dishwasher.

Verification:

The measurement and verification of the time for extraction shall be made using a standardized, accurate and reproducible measurement procedure, which takes into account the generally recognised state of the art measurement methods.

The availability of spare parts for purchasing and information shall be proved by the manufacturer.

Alternatively other potential product's policy criteria could be based on extended warranties on the DW or its key parts, as following.

Potential product's policy criteria: Extended warranty of key parts of the DW

Functional key parts of the DW (including pumps, electronics, heating system and door panel)[69] shall have a minimum warranty time (compared to the basic product's warranty[70]) of 2 years[71].

Verification:

Commitment of the manufacturers for the replacement/repairing of the key components free of charge for the consumers (including costs for labour).

It is furthermore highlighted that the availability of specific standards on the durability of DWs (or some of their components) could allow contributing to the prolongation of the lifetime of the products. Other potential product's policy criteria for DWs could be set based on specific standards for durability, when available. Although currently some testing procedures for durability have been developed by manufacturers, no international standard has been identified as already available. Assessment of potential benefits of the requirement at the case-study level

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[66] This list is only exemplary. Other key parts can be included, on the basis of a more comprehensive analysis of the product group, and involving associations of reuse/recycling companies, manufacturers and association of consumers.

[67] This criterion refers to non-destructive disassembly meaning: the part should be suitable for disassembly without damaging the part itself and other parts of the product.

[68] The threshold times for non-destructive disassembly are here illustrative. Some more detailed figures, differentiated also for different components, should refer to detailed data about the maintenance and repairing treatments of DW.

[69] This list is only exemplary. Other key parts can be included, on the basis of a more comprehensive analysis of the product group, and involving associations of reuse/recycling companies, manufacturers and association of consumers.

[70] European product's warranty as regulated by the Directive 1999/44/EC [EU, 1999].

[71] The time frame of the extended warranty is here only illustrative. More precise figures should be set according to an extended analysis of products in the market, involving, as far as possible, also manufacturers.

The environmental benefits of extending lifetime of a DW for some years have been calculated in section 3.7. For example, extending by 4 years the lifetime of a DW reduces up to 3% the environmental impact of GWP.

However, the potential requirements on the durability of DW cannot be simply linked to the measures for the extension of the lifetime of devices. A proper estimation would require sufficient statistical data on the operation time of devices and potential failures.

The analysis in the previous sections considered an average life of 12 years. However, according also to data from other references, the option of extending the lifetime by 3 years (from 12 to 15 years) is plausible also due to maintenance/repairing.

For example, according to the literature survey, some ranges of lifetimes of DW are:

- 12 - 15 years [VHK, 2005]
- 12.5 years [ISIS, 2007]
- 10 - 15 years [Johansson and Luttropp, 2009];
- 12 years [Zhifeng et al., 2012]

In addition, according to data on the repairing rates of DW[72] from an association of consumers, about 20% of the devices suffer a repair within the first 4 years of operation. Such preliminary failures could be avoided for example by extending the overall warranty of the product up to 4 years.

In the light of this information, the benefits of including a potential requirement for the durability of DW are assessed making the following assumptions:

- Premature failures could be avoided by extending the warranty of DW. We estimate that up to 20% of the devices could extend their lifetime by 4 years (delaying the purchase of a DW with the same energy efficiency, under the “low repairing scenario”).
- The design for reversible disassembly of key components (namely pumps, printed circuit boards, heating system, thermostat, valves, filters, hoses, spray arms, door panel, seals and racks) and the availability of spare parts could facilitate the repairing of 80% of the DWs (extending the lifetime by 3 years, and delaying the purchase of a new DW 5% to 10%[73] more energy efficient, under the “high repairing scenario”).

The life cycle environmental benefits so calculated are illustrated in Table 30 (positive values mean benefits). As observed, the extension of the lifetime of a DW generally allows a reduction of the environmental impacts for the majority of the impact categories[74]. The categories with the greatest environmental impact reduction are Freshwater eutrophication, Abiotic Depletion elements and ecotoxicity.

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[72] From: http://www.warrantyweek.com/archive/ww20061121.html ; access April 2013)

[73] It is assumed that half of DW would be substituted by a new device 5% more energy efficient and the other half by a device 10% more energy efficient one.

[74] The lifetime extension is producing low additional burdens for the Acidification potential, Ozone depletion potential and Ionizing radiations, being these impact categories largely dominated by the consumption during the use phase.

Table 30 Benefits of extending lifetime of DW

Benefits of extending lifetime through product's requirements		
Abiotic Depletion (ADP_{el})	[kg $Sb_{Equiv.}$]	2.9E-04
Abiotic Depletion (ADP_{fossil})	[MJ]	8.5E+01
Acidification Potential (AP)	[kg $SO_{2\text{-}Equiv.}$]	-1.3E-02
Global Warming Potential (GWP)	[kg $CO_{2\text{-}Equiv.}$]	1.5E+01
Ozone Layer Depletion Potential (ODP)	[kg $R11_{\text{-}Equiv.}$]	-2.4E-06
Terrestrial eutrophication	[m^2 UES]	6.6E-01
Freshwater eutrophication	[kg P eq]	6.8E-04
Ionising radiation	[kg $U_{235\ eq}$]	-5.6E+06
Marine eutrophication	[kg $N_{Equiv.}$]	9.9E-03
Particulate matter formation	[kg $PM_{10\ eq}$]	1.9E-02
Photochemical oxidant formation	[kg NMVOC]	2.9E-02
Ecotoxicity	[PAF m^3.day]	1.6E-01
Human toxicity	[cases]	1.3E-10

b) Assessment of potential benefits of the requirement at the product group level

The potential benefits for the overall product group are calculated by considering the benefits for a single device and the total number of DWs currently produced that will be wasted at their EoL (the number of dishwasher yearly sold is assumed 8.2[75] [million/year]).

The benefits were calculated (Table 31) and normalized to the life cycle impacts of the product group and also compared with the benefits obtained for the Ecodesign implementing measures currently in force for the dishwashers (estimated in 2 TWh[76], [77, 78])

The benefits are ranging from 0.4% (human toxicity) to 16% (Freshwater eutrophication) of the life cycle impacts of the product group. Compared to the current Ecodesign implementing measures for DW, the benefits related to the extension of the lifetime are much higher for the Abiotic depletion element, freshwater eutrophication and ecotoxicity; furthermore, for the GWP impact category, the environmental benefits related to the potential measures on durability would amount to about 11% of the benefits that would be achieved by the previously cited implementing measures on household DW.

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[75] Annual dishwashers sold in 2012. "EUROSTAT - Statistics on the production of manufactured goods". http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/tables_excel, last updated February 2013).

[76] Commission Regulation (EU) No 1016/2010 of 10 November 2010 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household dishwashers.

[77] (http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/index_en.htm ; access April 2013)

[78] Overall environmental benefits related to the 2 TWh energy saving have been calculated assuming the average EU27 power grid mix at the consumer (life cycle inventory data from [ELCD, 2010])

Table 31 Overall benefits of extending lifetime of DW

	A. Benefits of extending lifetime via product's requirements		B. Life Cycle impacts of the product group	Fraction (A/B) [%]	C. Benefits of implementing measures currently in force	Fraction (A/C) [%]
Abiotic Depletion (ADP_{el})	[10^3 kg $Sb_{Equiv.}$]	2.4E+00	2.6E+01	9.2%	8.0E-02	3052.3%
Abiotic Depletion (ADP_{fossil})	[TJ]	7.1E+02	1.4E+05	0.5%	1.1E+04	6.2%
Acidification Potential (AP)	[10^3 kg $SO_{2\text{-}Equiv.}$]	-1.1E+02	1.1E+05	-0.1%	9.1E+03	-1.2%
Global Warming Potential (GWP)	[10^3 kg $CO_{2\text{-}Equiv.}$]	1.2E+05	1.5E+07	0.8%	1.2E+06	10.6%
Ozone Layer Depletion Potential (ODP)	[10^3 kg $R11_{\text{-}Equiv.}$]	-2.0E-02	3.4E+00	-0.6%	2.9E-01	-7.0%
Terrestrial eutrophication	[10^3 m^2 UES]	5.5E+03	6.9E+05	0.8%	5.4E+04	10.1%
Freshwater eutrophication	[10^3 kg P eq]	5.6E+00	3.4E+01	16.3%	6.5E-01	856.2%
Ionising radiation	[10^3 kg $U_{235\ eq}$]	-4.6E+10	3.8E+12	-1.2%	3.2E+11	-14.1%
Marine eutrophication	[10^3 kg $N_{Equiv.}$]	8.1E+01	1.1E+04	0.8%	8.3E+02	9.8%
Particulate matter formation	[10^3 kg $PM_{10\ eq}$]	1.5E+02	2.5E+04	0.6%	2.0E+03	7.8%
Photochemical oxidant formation	[10^3 kg NMVOC]	2.4E+02	3.5E+04	0.7%	2.7E+03	8.9%
Ecotoxicity	[10^3 PAF m^3.day]	1.4E+03	1.9E+04	7.1%	3.7E+02	368.8%
Human toxicity	[10^3 cases]	1.1E-06	2.6E-04	0.4%	2.1E-05	5.2%

Finally, we calculate the masses of materials potentially saved by extending the lifetime of DW. These can be calculated, based on the number of devices used for a certain time-frame, in the base-case scenario and the extended lifetime scenario [Ardente et al., 2012]:

Formula 1
$$n_{base\text{-}case} = \left(\frac{X}{lifetine_{base\text{-}case}} \right)$$

Formula 2
$$n_{extended} = \left(\frac{X}{lifetime_{extended}} \right)$$

Where:

- $n_{base\text{-}case}$ = number of products, in the base-case scenario, used for the time-frame of X years [dimensionless];
- $n_{extended}$ = number of products, in the extended lifetime scenario, used in the time-frame of X years [dimensionless];
- X = time-frame for the analysis [year];
- $Lifetime_{base\text{-}case}$ = lifetime of the product in the base-case scenario [year];
- $Lifetime_{extended}$ = extended lifetime of the product in the new scenario [year].

The number of saved products for a considered timeframe as result of extending their lifetime is:

Formula 3
$$Saved\ products = \left(\frac{X}{lifetine_{base\text{-}case}} - \frac{X}{lifetime_{extended}} \right)$$

The number of saved products per year[79] is obtained suing formula 4:

Formula 4
$$Saved\ products\ (per\ year) = \frac{Saved\ products}{X} = \left(\frac{1}{lifetine_{base-case}} - \frac{1}{lifetime_{extended}} \right)$$

It is important to highlight that this number (from formula 4) is independent from the considered time-frame "X".

For the present analysis, it is assumed that the operating time of 12 years of DW, while the lifetime extension of devices is: 4 years (for 20% of devices) and 3 years (for the remaining). Table 32 shows the amount of masses of some materials saved yearly. The results are also normalized according to the overall amount of materials used in the EU27[80].

Table 32 Amount of saved material thanks to the extended lifetime of DW

Materials	A. Yearly saved masses [10^3 kg/year]	B. Materials used in the EU27 [ton/year]	Fraction (A/B) [%]
Acryl-Butadien-Styrol (ABS)	109	752,039	0.014%
Aluminium	39	5,020,336	0.001%
Copper	127	3,525,910	0.004%
Gold	0.002	130	0.002%
Palladium	0.001	720	0.0002%
Polyamide (PA)	58	2,543,222	0.002%
Polypropylen - various (PP)	720	8,727,089	0.008%
Polystyrene (PS)	74	1,851,821	0.004%
Silver	0.01	12,050	0.0001%
Steel	3,941	79,926,821	0.005%

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[79] The number of saved products per year represents the number of DW that are avoided, thanks to the prolonged lifetime of devices, in order to deliver the same function (washing cycles) for the considered reference time-span of the analysis.

[80] Values from [Ardente et Mathieux, 2012b]

Conclusions

The present study analysed possible measures to improve the resource efficiency of dishwashers, especially at their end of life. The EoL scenarios analysed were: scenario 1) shredding and scenario 2) a combined treatment which includes dismantling with preliminary and fine shredding.

The results of the environmental impact assessed using the REAPro method show almost the same recyclability and recoverability rates (in mass) for both scenarios. Concerning the recyclability benefit rate, some relevant differences have been observed for some impact categories (e.g. Abiotic Depletion Potential elements, ecotoxicity and freshwater eutrophication). These differences are related to the different treatments of some key components. In particular the preventive extraction of printed Circuit Boards (PCBs) and LCD screens (when included) will allow higher recycling rates of copper and some precious metals like gold, palladium and silver and avoid the dispersion of several potential hazardous substances that they could contain.

The REAPro method also included the assessment of the energy recoverability benefit rate and the recycled content benefit index, mainly focused on the recycling and recovery of some plastic parts. However, these criteria are found to be not relevant for the considered case-study.

Some potential measures have been therefore proposed to improve resource efficiency: one measure about the design for disassembly and another measure to improve the product durability.

It has been estimated that the improvement of the design for repairing and the extension of the warranty time of key components of the DWs could reduce up to 30% some life cycle environmental impacts, as abiotic depletion of elements (ADP_{el}), freshwater eutrophication and ecotoxicity.

The implementation of a potential requirement on the design for the extraction of key components of the DW would allow the additional yearly recovery of about 1.031 tonnes of copper, 247 kg of silver, 50 kg of gold and 27 kg of palladium, which will have a potential economic benefit of 6.3 to 6.6 Million €.

It is also pointed out that the enforcement and verification of a requirement on the extractability of key components requires a standard method to measure the time for extraction[81]. Some relevant standardization activities have already been kicked-off in the context of the Task Force "Eco-design Coordination Group Resource efficiency" of CEN/CENELEC.

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[81] A potential method for the measurement of the time for extraction of key components is discussed in a separate report titled "*Feasibility study on a standardised method for repeatable measurements of the time for extraction of certain target parts from an Electrical and Electronic Equipment*" (draft under development – September 2013).

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Annex 1 – Durability of Dishwasher case-study

Table A1.1. Simplified Durability Index of the dishwasher for the “Low Repairing Scenario (LRS)” and the “high Repairing Scenario (HRS)”

D'n [ADP$_{el}$] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	3.2%	11.2%	19.1%	27.1%
	99%	3.2%	11.2%	19.1%	27.1%
	98%	3.2%	11.2%	19.1%	27.1%
	97%	3.2%	11.1%	19.1%	27.1%
	96%	3.2%	11.1%	19.1%	27.1%
	95%	3.2%	11.1%	19.1%	27.0%
	94%	3.2%	11.1%	19.1%	27.0%
	93%	3.2%	11.1%	19.1%	27.0%
	92%	3.2%	11.1%	19.1%	27.0%
	91%	3.2%	11.1%	19.0%	27.0%
	90%	3.2%	11.1%	19.0%	27.0%
	89%	3.2%	11.1%	19.0%	27.0%
	88%	3.1%	11.1%	19.0%	26.9%
	87%	3.1%	11.1%	19.0%	26.9%
	86%	3.1%	11.1%	19.0%	26.9%
	85%	3.1%	11.1%	19.0%	26.9%

D'n [ADP$_{fossil}$] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.2%	1.8%	2.4%
	99%	0.5%	1.0%	1.6%	2.1%
	98%	0.4%	0.9%	1.3%	1.8%
	97%	0.3%	0.7%	1.1%	1.5%
	96%	0.3%	0.6%	0.9%	1.2%
	95%	0.2%	0.4%	0.6%	0.9%
	94%	0.1%	0.3%	0.4%	0.5%
	93%	0.0%	0.1%	0.2%	0.2%
	92%	0.0%	-0.1%	-0.1%	-0.1%
	91%	-0.1%	-0.2%	-0.3%	-0.4%
	90%	-0.2%	-0.4%	-0.5%	-0.7%
	89%	-0.3%	-0.5%	-0.8%	-1.0%
	88%	-0.4%	-0.7%	-1.0%	-1.3%
	87%	-0.4%	-0.8%	-1.2%	-1.6%
	86%	-0.5%	-1.0%	-1.5%	-1.9%
	85%	-0.6%	-1.1%	-1.7%	-2.2%

D'n [AP] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.4%	0.8%	1.3%	1.7%
	99%	0.3%	0.7%	1.0%	1.4%
	98%	0.2%	0.5%	0.8%	1.1%
	97%	0.2%	0.4%	0.5%	0.7%
	96%	0.1%	0.2%	0.3%	0.4%
	95%	0.0%	0.0%	0.1%	0.1%
	94%	-0.1%	-0.1%	-0.2%	-0.2%
	93%	-0.1%	-0.3%	-0.4%	-0.5%
	92%	-0.2%	-0.4%	-0.6%	-0.8%
	91%	-0.3%	-0.6%	-0.9%	-1.2%
	90%	-0.4%	-0.7%	-1.1%	-1.5%
	89%	-0.5%	-0.9%	-1.3%	-1.8%
	88%	-0.5%	-1.1%	-1.6%	-2.1%
	87%	-0.6%	-1.2%	-1.8%	-2.4%
	86%	-0.7%	-1.4%	-2.1%	-2.7%
	85%	-0.8%	-1.5%	-2.3%	-3.1%

D'n [ADP$_{el}$] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	-11.2%	-3.2%	4.8%	12.8%
	99%	-11.2%	-3.2%	4.8%	12.8%
	98%	-11.2%	-3.2%	4.8%	12.7%
	97%	-11.2%	-3.2%	4.8%	12.7%
	96%	-11.2%	-3.2%	4.8%	12.7%
	95%	-11.2%	-3.2%	4.7%	12.7%
	94%	-11.2%	-3.2%	4.7%	12.7%
	93%	-11.2%	-3.2%	4.7%	12.7%
	92%	-11.2%	-3.2%	4.7%	12.7%
	91%	-11.2%	-3.2%	4.7%	12.6%
	90%	-11.2%	-3.3%	4.7%	12.6%
	89%	-11.2%	-3.3%	4.7%	12.6%
	88%	-11.2%	-3.3%	4.7%	12.6%
	87%	-11.2%	-3.3%	4.7%	12.6%
	86%	-11.2%	-3.3%	4.6%	12.6%
	85%	-11.2%	-3.3%	4.6%	12.6%

D'n [ADP$_{fossil}$] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.5%	1.1%	1.8%	2.4%
	99%	0.5%	1.0%	1.5%	2.1%
	98%	0.4%	0.8%	1.3%	1.7%
	97%	0.3%	0.7%	1.1%	1.4%
	96%	0.2%	0.5%	0.8%	1.1%
	95%	0.2%	0.4%	0.6%	0.8%
	94%	0.1%	0.2%	0.4%	0.5%
	93%	0.0%	0.1%	0.1%	0.2%
	92%	-0.1%	-0.1%	-0.1%	-0.1%
	91%	-0.2%	-0.2%	-0.3%	-0.4%
	90%	-0.2%	-0.4%	-0.6%	-0.7%
	89%	-0.3%	-0.6%	-0.8%	-1.0%
	88%	-0.4%	-0.7%	-1.0%	-1.3%
	87%	-0.5%	-0.9%	-1.3%	-1.6%
	86%	-0.5%	-1.0%	-1.5%	-2.0%
	85%	-0.6%	-1.2%	-1.7%	-2.3%

D'n [AP] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.4%	0.8%	1.2%	1.7%
	99%	0.3%	0.6%	1.0%	1.3%
	98%	0.2%	0.5%	0.8%	1.0%
	97%	0.1%	0.3%	0.5%	0.7%
	96%	0.1%	0.2%	0.3%	0.4%
	95%	0.0%	0.0%	0.0%	0.1%
	94%	-0.1%	-0.1%	-0.2%	-0.2%
	93%	-0.2%	-0.3%	-0.4%	-0.5%
	92%	-0.3%	-0.5%	-0.7%	-0.9%
	91%	-0.3%	-0.6%	-0.9%	-1.2%
	90%	-0.4%	-0.8%	-1.1%	-1.5%
	89%	-0.5%	-0.9%	-1.4%	-1.8%
	88%	-0.6%	-1.1%	-1.6%	-2.1%
	87%	-0.6%	-1.2%	-1.8%	-2.4%
	86%	-0.7%	-1.4%	-2.1%	-2.8%
	85%	-0.8%	-1.6%	-2.3%	-3.1%

Table A1.1.(continue) Simplified Durability Index of the dishwasher for the “Low Repairing Scenario (LRS)” and the “high Repairing Scenario (HRS)”

D'n [GWP] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.7%	1.4%	2.1%	2.8%
	99%	0.6%	1.2%	1.9%	2.5%
	98%	0.5%	1.1%	1.6%	2.2%
	97%	0.4%	0.9%	1.4%	1.9%
	96%	0.4%	0.8%	1.2%	1.6%
	95%	0.3%	0.6%	0.9%	1.3%
	94%	0.2%	0.5%	0.7%	1.0%
	93%	0.1%	0.3%	0.5%	0.7%
	92%	0.1%	0.2%	0.3%	0.4%
	91%	0.0%	0.0%	0.0%	0.0%
	90%	-0.1%	-0.1%	-0.2%	-0.3%
	89%	-0.2%	-0.3%	-0.4%	-0.6%
	88%	-0.2%	-0.5%	-0.7%	-0.9%
	87%	-0.3%	-0.6%	-0.9%	-1.2%
	86%	-0.4%	-0.8%	-1.1%	-1.5%
	85%	-0.5%	-0.9%	-1.3%	-1.8%

D'n [ODP] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.3%	0.5%	0.8%	1.1%
	99%	0.2%	0.4%	0.6%	0.8%
	98%	0.1%	0.2%	0.3%	0.5%
	97%	0.0%	0.1%	0.1%	0.1%
	96%	-0.1%	-0.1%	-0.1%	-0.2%
	95%	-0.1%	-0.3%	-0.4%	-0.5%
	94%	-0.2%	-0.4%	-0.6%	-0.8%
	93%	-0.3%	-0.6%	-0.9%	-1.2%
	92%	-0.4%	-0.7%	-1.1%	-1.5%
	91%	-0.5%	-0.9%	-1.4%	-1.8%
	90%	-0.5%	-1.1%	-1.6%	-2.1%
	89%	-0.6%	-1.2%	-1.8%	-2.4%
	88%	-0.7%	-1.4%	-2.1%	-2.8%
	87%	-0.8%	-1.6%	-2.3%	-3.1%
	86%	-0.9%	-1.7%	-2.6%	-3.4%
	85%	-0.9%	-1.9%	-2.8%	-3.7%

D'n [Terr.Eutroph.] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.7%	1.4%	2.1%	2.8%
	99%	0.6%	1.2%	1.8%	2.4%
	98%	0.5%	1.1%	1.6%	2.1%
	97%	0.4%	0.9%	1.4%	1.8%
	96%	0.4%	0.7%	1.1%	1.5%
	95%	0.3%	0.6%	0.9%	1.2%
	94%	0.2%	0.4%	0.7%	0.9%
	93%	0.1%	0.3%	0.5%	0.6%
	92%	0.0%	0.1%	0.2%	0.3%
	91%	0.0%	0.0%	0.0%	0.0%
	90%	-0.1%	-0.2%	-0.2%	-0.3%
	89%	-0.2%	-0.3%	-0.5%	-0.6%
	88%	-0.3%	-0.5%	-0.7%	-0.9%
	87%	-0.3%	-0.6%	-0.9%	-1.2%
	86%	-0.4%	-0.8%	-1.2%	-1.5%
	85%	-0.5%	-0.9%	-1.4%	-1.8%

D'n [Freshw. eutroph.] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	4.2%	10.7%	17.1%	23.6%
	99%	4.2%	10.6%	17.1%	23.5%
	98%	4.2%	10.6%	17.0%	23.5%
	97%	4.2%	10.6%	17.0%	23.4%
	96%	4.1%	10.5%	16.9%	23.3%
	95%	4.1%	10.5%	16.9%	23.2%
	94%	4.1%	10.5%	16.8%	23.2%
	93%	4.1%	10.4%	16.8%	23.1%
	92%	4.1%	10.4%	16.7%	23.0%
	91%	4.0%	10.3%	16.6%	22.9%
	90%	4.0%	10.3%	16.6%	22.9%
	89%	4.0%	10.3%	16.5%	22.8%
	88%	4.0%	10.2%	16.5%	22.7%
	87%	4.0%	10.2%	16.4%	22.6%
	86%	4.0%	10.2%	16.4%	22.6%
	85%	3.9%	10.1%	16.3%	22.5%

D'n [GWP] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	2.0%	2.8%
	99%	0.6%	1.2%	1.8%	2.4%
	98%	0.5%	1.0%	1.6%	2.1%
	97%	0.4%	0.9%	1.4%	1.8%
	96%	0.3%	0.7%	1.1%	1.5%
	95%	0.2%	0.6%	0.9%	1.2%
	94%	0.2%	0.4%	0.7%	0.9%
	93%	0.1%	0.3%	0.4%	0.6%
	92%	0.0%	0.1%	0.2%	0.3%
	91%	-0.1%	0.0%	0.0%	0.0%
	90%	-0.1%	-0.2%	-0.2%	-0.3%
	89%	-0.2%	-0.3%	-0.5%	-0.6%
	88%	-0.3%	-0.5%	-0.7%	-0.9%
	87%	-0.4%	-0.6%	-0.9%	-1.2%
	86%	-0.4%	-0.8%	-1.2%	-1.5%
	85%	-0.5%	-1.0%	-1.4%	-1.8%

D'n [ODP] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.2%	0.5%	0.8%	1.1%
	99%	0.2%	0.4%	0.6%	0.8%
	98%	0.1%	0.2%	0.3%	0.4%
	97%	0.0%	0.0%	0.1%	0.1%
	96%	-0.1%	-0.1%	-0.2%	-0.2%
	95%	-0.2%	-0.3%	-0.4%	-0.5%
	94%	-0.2%	-0.4%	-0.6%	-0.8%
	93%	-0.3%	-0.6%	-0.9%	-1.2%
	92%	-0.4%	-0.8%	-1.1%	-1.5%
	91%	-0.5%	-0.9%	-1.4%	-1.8%
	90%	-0.6%	-1.1%	-1.6%	-2.1%
	89%	-0.6%	-1.2%	-1.9%	-2.5%
	88%	-0.7%	-1.4%	-2.1%	-2.8%
	87%	-0.8%	-1.6%	-2.3%	-3.1%
	86%	-0.9%	-1.7%	-2.6%	-3.4%
	85%	-1.0%	-1.9%	-2.8%	-3.7%

D'n [Terr. Eutroph.] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	2.0%	2.7%
	99%	0.5%	1.2%	1.8%	2.4%
	98%	0.5%	1.0%	1.6%	2.1%
	97%	0.4%	0.9%	1.3%	1.8%
	96%	0.3%	0.7%	1.1%	1.5%
	95%	0.2%	0.6%	0.9%	1.2%
	94%	0.2%	0.4%	0.6%	0.9%
	93%	0.1%	0.2%	0.4%	0.6%
	92%	0.0%	0.1%	0.2%	0.3%
	91%	-0.1%	-0.1%	0.0%	0.0%
	90%	-0.1%	-0.2%	-0.3%	-0.3%
	89%	-0.2%	-0.4%	-0.5%	-0.6%
	88%	-0.3%	-0.5%	-0.7%	-1.0%
	87%	-0.4%	-0.7%	-1.0%	-1.3%
	86%	-0.5%	-0.8%	-1.2%	-1.6%
	85%	-0.5%	-1.0%	-1.4%	-1.9%

D'n [Freshw. eutroph.] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	2.0%	8.4%	14.9%	21.4%
	99%	1.9%	8.4%	14.8%	21.3%
	98%	1.9%	8.3%	14.8%	21.2%
	97%	1.9%	8.3%	14.7%	21.1%
	96%	1.9%	8.3%	14.7%	21.1%
	95%	1.9%	8.2%	14.6%	21.0%
	94%	1.8%	8.2%	14.6%	20.9%
	93%	1.8%	8.2%	14.5%	20.8%
	92%	1.8%	8.1%	14.4%	20.8%
	91%	1.8%	8.1%	14.4%	20.7%
	90%	1.8%	8.1%	14.3%	20.6%
	89%	1.7%	8.0%	14.3%	20.5%
	88%	1.7%	8.0%	14.2%	20.5%
	87%	1.7%	7.9%	14.2%	20.4%
	86%	1.7%	7.9%	14.1%	20.3%
	85%	1.7%	7.9%	14.1%	20.2%

Table A1.1.(continue) Simplified Durability Index of the dishwasher for the “Low Repairing Scenario (LRS)” and the “high Repairing Scenario (HRS)”

D'n [Ionising rad.] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.1%	0.2%	0.3%	0.3%
	99%	0.0%	0.0%	0.0%	0.0%
	98%	-0.1%	-0.2%	-0.2%	-0.3%
	97%	-0.2%	-0.3%	-0.5%	-0.6%
	96%	-0.2%	-0.5%	-0.7%	-1.0%
	95%	-0.3%	-0.7%	-1.0%	-1.3%
	94%	-0.4%	-0.8%	-1.2%	-1.6%
	93%	-0.5%	-1.0%	-1.5%	-2.0%
	92%	-0.6%	-1.1%	-1.7%	-2.3%
	91%	-0.7%	-1.3%	-2.0%	-2.6%
	90%	-0.7%	-1.5%	-2.2%	-2.9%
	89%	-0.8%	-1.6%	-2.5%	-3.3%
	88%	-0.9%	-1.8%	-2.7%	-3.6%
	87%	-1.0%	-2.0%	-3.0%	-3.9%
	86%	-1.1%	-2.1%	-3.2%	-4.3%
	85%	-1.2%	-2.3%	-3.4%	-4.6%

D'n [Marine eutroph.] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.7%	1.3%	2.0%	2.7%
	99%	0.6%	1.2%	1.8%	2.4%
	98%	0.5%	1.0%	1.6%	2.1%
	97%	0.4%	0.9%	1.3%	1.8%
	96%	0.3%	0.7%	1.1%	1.5%
	95%	0.3%	0.6%	0.9%	1.2%
	94%	0.2%	0.4%	0.7%	0.9%
	93%	0.1%	0.3%	0.4%	0.6%
	92%	0.0%	0.1%	0.2%	0.3%
	91%	0.0%	0.0%	0.0%	0.0%
	90%	-0.1%	-0.2%	-0.3%	-0.3%
	89%	-0.2%	-0.3%	-0.5%	-0.6%
	88%	-0.3%	-0.5%	-0.7%	-0.9%
	87%	-0.3%	-0.6%	-1.0%	-1.3%
	86%	-0.4%	-0.8%	-1.2%	-1.6%
	85%	-0.5%	-1.0%	-1.4%	-1.9%

D'n [Particulate matter] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	1.9%	2.6%
	99%	0.5%	1.1%	1.7%	2.2%
	98%	0.5%	1.0%	1.4%	1.9%
	97%	0.4%	0.8%	1.2%	1.6%
	96%	0.3%	0.6%	1.0%	1.3%
	95%	0.2%	0.5%	0.8%	1.0%
	94%	0.1%	0.3%	0.5%	0.7%
	93%	0.1%	0.2%	0.3%	0.4%
	92%	0.0%	0.0%	0.1%	0.1%
	91%	-0.1%	-0.1%	-0.2%	-0.2%
	90%	-0.2%	-0.3%	-0.4%	-0.5%
	89%	-0.2%	-0.4%	-0.6%	-0.8%
	88%	-0.3%	-0.6%	-0.9%	-1.1%
	87%	-0.4%	-0.7%	-1.1%	-1.4%
	86%	-0.5%	-0.9%	-1.3%	-1.8%
	85%	-0.5%	-1.0%	-1.6%	-2.1%

D'n [Photoch. Oxid.] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	2.0%	2.6%
	99%	0.6%	1.1%	1.7%	2.3%
	98%	0.5%	1.0%	1.5%	2.0%
	97%	0.4%	0.8%	1.3%	1.7%
	96%	0.3%	0.7%	1.1%	1.4%
	95%	0.2%	0.5%	0.8%	1.1%
	94%	0.2%	0.4%	0.6%	0.8%
	93%	0.1%	0.2%	0.4%	0.5%
	92%	0.0%	0.1%	0.1%	0.2%
	91%	-0.1%	-0.1%	-0.1%	-0.1%
	90%	-0.1%	-0.2%	-0.3%	-0.4%
	89%	-0.2%	-0.4%	-0.6%	-0.7%
	88%	-0.3%	-0.5%	-0.8%	-1.0%
	87%	-0.4%	-0.7%	-1.0%	-1.3%
	86%	-0.4%	-0.8%	-1.2%	-1.7%
	85%	-0.5%	-1.0%	-1.5%	-2.0%

D'n [Ionising rad.] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.1%	0.2%	0.3%	0.3%
	99%	0.0%	0.0%	0.0%	0.0%
	98%	-0.1%	-0.2%	-0.2%	-0.3%
	97%	-0.2%	-0.3%	-0.5%	-0.6%
	96%	-0.3%	-0.5%	-0.7%	-1.0%
	95%	-0.3%	-0.7%	-1.0%	-1.3%
	94%	-0.4%	-0.8%	-1.2%	-1.6%
	93%	-0.5%	-1.0%	-1.5%	-2.0%
	92%	-0.6%	-1.2%	-1.7%	-2.3%
	91%	-0.7%	-1.3%	-2.0%	-2.6%
	90%	-0.7%	-1.5%	-2.2%	-3.0%
	89%	-0.8%	-1.6%	-2.5%	-3.3%
	88%	-0.9%	-1.8%	-2.7%	-3.6%
	87%	-1.0%	-2.0%	-3.0%	-3.9%
	86%	-1.1%	-2.1%	-3.2%	-4.3%
	85%	-1.2%	-2.3%	-3.5%	-4.6%

D'n [Marine eutroph.] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	2.0%	2.7%
	99%	0.5%	1.1%	1.8%	2.4%
	98%	0.5%	1.0%	1.5%	2.1%
	97%	0.4%	0.8%	1.3%	1.8%
	96%	0.3%	0.7%	1.1%	1.5%
	95%	0.2%	0.5%	0.8%	1.2%
	94%	0.2%	0.4%	0.6%	0.8%
	93%	0.1%	0.2%	0.4%	0.5%
	92%	0.0%	0.1%	0.2%	0.2%
	91%	-0.1%	-0.1%	-0.1%	-0.1%
	90%	-0.2%	-0.2%	-0.3%	-0.4%
	89%	-0.2%	-0.4%	-0.5%	-0.7%
	88%	-0.3%	-0.5%	-0.8%	-1.0%
	87%	-0.4%	-0.7%	-1.0%	-1.3%
	86%	-0.5%	-0.8%	-1.2%	-1.6%
	85%	-0.5%	-1.0%	-1.4%	-1.9%

D'n [Particulate matter] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.2%	1.9%	2.5%
	99%	0.5%	1.1%	1.6%	2.2%
	98%	0.4%	0.9%	1.4%	1.9%
	97%	0.3%	0.8%	1.2%	1.6%
	96%	0.3%	0.6%	0.9%	1.3%
	95%	0.2%	0.5%	0.7%	1.0%
	94%	0.1%	0.3%	0.5%	0.7%
	93%	0.0%	0.1%	0.3%	0.4%
	92%	0.0%	0.0%	0.0%	0.1%
	91%	-0.1%	-0.2%	-0.2%	-0.3%
	90%	-0.2%	-0.3%	-0.4%	-0.6%
	89%	-0.3%	-0.5%	-0.7%	-0.9%
	88%	-0.4%	-0.6%	-0.9%	-1.2%
	87%	-0.4%	-0.8%	-1.1%	-1.5%
	86%	-0.5%	-0.9%	-1.4%	-1.8%
	85%	-0.6%	-1.1%	-1.6%	-2.1%

D'n [Photoch. Oxid.] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.3%	1.9%	2.6%
	99%	0.5%	1.1%	1.7%	2.3%
	98%	0.4%	1.0%	1.5%	2.0%
	97%	0.4%	0.8%	1.2%	1.7%
	96%	0.3%	0.6%	1.0%	1.4%
	95%	0.2%	0.5%	0.8%	1.1%
	94%	0.1%	0.3%	0.6%	0.8%
	93%	0.1%	0.2%	0.3%	0.5%
	92%	0.0%	0.0%	0.1%	0.1%
	91%	-0.1%	-0.1%	-0.1%	-0.2%
	90%	-0.2%	-0.3%	-0.4%	-0.5%
	89%	-0.3%	-0.4%	-0.6%	-0.8%
	88%	-0.3%	-0.6%	-0.8%	-1.1%
	87%	-0.4%	-0.7%	-1.1%	-1.4%
	86%	-0.5%	-0.9%	-1.3%	-1.7%
	85%	-0.6%	-1.0%	-1.5%	-2.0%

Table A1.1. Simplified Durability Index for dishwasher case-study (Low Repairing Scenario) (Continue)

D'n [Ecotoxicity] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	2.6%	9.0%	15.4%	21.9%
	99%	2.6%	9.0%	15.4%	21.8%
	98%	2.5%	8.9%	15.3%	21.7%
	97%	2.5%	8.9%	15.3%	21.6%
	96%	2.5%	8.9%	15.2%	21.6%
	95%	2.5%	8.8%	15.2%	21.5%
	94%	2.5%	8.8%	15.1%	21.4%
	93%	2.4%	8.7%	15.0%	21.3%
	92%	2.4%	8.7%	15.0%	21.3%
	91%	2.4%	8.7%	14.9%	21.2%
	90%	2.4%	8.6%	14.9%	21.1%
	89%	2.4%	8.6%	14.8%	21.0%
	88%	2.4%	8.6%	14.8%	21.0%
	87%	2.3%	8.5%	14.7%	20.9%
	86%	2.3%	8.5%	14.6%	20.8%
	85%	2.3%	8.4%	14.6%	20.7%

D'n [Human toxicity] - (LRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.6%	1.1%	1.7%	2.3%
	99%	0.5%	1.0%	1.5%	2.0%
	98%	0.4%	0.8%	1.3%	1.7%
	97%	0.3%	0.7%	1.0%	1.4%
	96%	0.2%	0.5%	0.8%	1.1%
	95%	0.2%	0.4%	0.6%	0.8%
	94%	0.1%	0.2%	0.3%	0.5%
	93%	0.0%	0.1%	0.1%	0.1%
	92%	-0.1%	-0.1%	-0.1%	-0.2%
	91%	-0.1%	-0.3%	-0.4%	-0.5%
	90%	-0.2%	-0.4%	-0.6%	-0.8%
	89%	-0.3%	-0.6%	-0.8%	-1.1%
	88%	-0.4%	-0.7%	-1.1%	-1.4%
	87%	-0.5%	-0.9%	-1.3%	-1.7%
	86%	-0.5%	-1.0%	-1.5%	-2.0%
	85%	-0.6%	-1.2%	-1.8%	-2.3%

D'n [Ecotoxicity] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	-9.0%	-2.5%	3.9%	10.3%
	99%	-9.0%	-2.6%	3.8%	10.2%
	98%	-9.0%	-2.6%	3.8%	10.2%
	97%	-9.0%	-2.7%	3.7%	10.1%
	96%	-9.1%	-2.7%	3.7%	10.0%
	95%	-9.1%	-2.7%	3.6%	9.9%
	94%	-9.1%	-2.8%	3.5%	9.9%
	93%	-9.1%	-2.8%	3.5%	9.8%
	92%	-9.1%	-2.9%	3.4%	9.7%
	91%	-9.2%	-2.9%	3.4%	9.6%
	90%	-9.2%	-2.9%	3.3%	9.6%
	89%	-9.2%	-3.0%	3.3%	9.5%
	88%	-9.2%	-3.0%	3.2%	9.4%
	87%	-9.2%	-3.0%	3.1%	9.3%
	86%	-9.2%	-3.1%	3.1%	9.3%
	85%	-9.3%	-3.1%	3.0%	9.2%

D'n [Human toxicity] - (HRS scenario)					
		"X" [years]			
		1	2	3	4
δ [%]	*100%*	0.5%	1.1%	1.7%	2.3%
	99%	0.4%	0.9%	1.5%	2.0%
	98%	0.4%	0.8%	1.2%	1.7%
	97%	0.3%	0.6%	1.0%	1.3%
	96%	0.2%	0.5%	0.8%	1.0%
	95%	0.1%	0.3%	0.5%	0.7%
	94%	0.1%	0.2%	0.3%	0.4%
	93%	0.0%	0.0%	0.1%	0.1%
	92%	-0.1%	-0.1%	-0.2%	-0.2%
	91%	-0.2%	-0.3%	-0.4%	-0.5%
	90%	-0.3%	-0.4%	-0.6%	-0.8%
	89%	-0.3%	-0.6%	-0.9%	-1.1%
	88%	-0.4%	-0.8%	-1.1%	-1.4%
	87%	-0.5%	-0.9%	-1.3%	-1.8%
	86%	-0.6%	-1.1%	-1.6%	-2.1%
	85%	-0.6%	-1.2%	-1.8%	-2.4%

European Commission
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