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Analysis of durability, reusability and reparability

Application to washing machines and dishwashers

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List of abbreviations

ADP	abiotic depletion potential
BoM	bill of materials
CEN	European Committee for Standardisation
Cenelec	European Committee for Electrotechnical Standardisation
DW	dishwasher
EEE	electrical and electronic equipment
EoL	end of life
ErP	energy-related product
EU	European Union
GWP	global warming potential
ILCD	International Reference Life Cycle Data System
JRC	Joint Research Centre
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
LRS	low repairing scenario
OEM	original equipment manufacturer
PCB	printed circuit board
ps	place settings
REAPro	resource efficiency assessment of products
REEE	reuse of electrical and electronic equipment
WEEE	waste electrical and electronic equipment
WM	washing machine

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Executive summary

This report has been developed within the project 'Technical support for environmental footprinting, material efficiency in product policy and the European Platform on LCA' (2013-2016), funded by the Directorate-General for the Environment. It aims to analyse material efficiency aspects, such as durability, reusability and reparability, for the two product groups washing machines (WM) and dishwashers (DW). The importance of such aspects in policy were recently reiterated by the EU action plan for the circular economy, especially on its section concerning consumption. The report has been subdivided into three parts, as described below.

Chapter 1: Analysis of the durability of WM and DW

The first chapter is devoted to the environmental assessment of the durability of WM and DW. This analysis is based on results obtained through the adoption of the resource efficiency assessment of products (REAPro) method of the Joint Research Centre. Moreover, this analysis represents an updated version of the methodology and the assessment illustrated in two former reports[1] and aligned to the ongoing preparatory studies[2] for the two product groups in the context of the ecodesign directive. The analysis aims at assessing the environmental consequence (impact or benefit) resulting from the lifetime extension, beyond the average lifetime expectancy, of two case-study devices. Several parameters have been considered in this analysis, including the technological progress and the possibility to have a newer product with a higher energy efficiency and different manufacturing impacts, and the incremental impacts required to manufacture a more durable product. The analysis is based on life cycle impact categories suggested by the International Reference Life Cycle Data System (ILCD). However, it was observed that the results for some impact categories had similar trends. Therefore, the analysis focused on three impact categories selected as being representative: the global warming potential, the abiotic depletion potential (for elements) and the freshwater eutrophication. Results showed that, for the global warming potential, prolonging the lifetime of the WM and DW case studies is environmentally beneficial when the potential replacement product has up to 15 % less energy consumption during the use. For the abiotic depletion potential impact, mainly influenced by the use of materials during the production phase, prolonging the lifetime of WM and DW was shown always to be beneficial, regardless of the energy efficiency of newer products. Freshwater eutrophication showed a great influence by the impact of the detergent used during the use phase; thus, prolonging the device's lifetime is still beneficial for this impact category, although the benefits are negligible compared to the life cycle impacts of the products.

Chapter 2: Analysis of the reusability of WM and DW

The second chapter introduces a detailed analysis of the processes for reuse of WM and DW. After an analysis of available standards for reuse, it presents the state of current treatments, principally based on visits and interviews with reuse companies. Some barriers to the reuse of products have been identified and discussed. This analysis allowed the identification of aspects (and strategies) that are relevant for the improvement of the products' 'reusability' (meaning the ability of the product to be reused). These aspects include: the design for the disassembly of certain crucial

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[1] Ardente, F., Mathieux, F., Sanfélix Forner, J., 2012. Report 1 — Analysis of Durability. doi:10.2788/72577 and Ardente, F., Talens Peiró, L., 2015. Report on benefits and impacts/costs of options for different potential material efficiency requirements for Dishwashers. doi:10.2788/28569.

[2] JRC-IPTS, 2016a. EU Preparatory study — Ecodesign for Dishwashers and JRC-IPTS, 2016b. EU Preparatory study — Ecodesign for Washing Machines and Washer Dryers.

components (e.g. the components that fail most frequently, as analysed in Chapter 3); the availability of spare parts; the provision of information by manufacturers (such as the product’s exploded diagram with a clear list of referenced parts, disassembly information, wiring diagrams and connection diagrams, test/diagnosis programs and error codes); and the possibility to re-program product’s software and erase error codes after the repair services. It was also observed that, in some cases, not all the refurbished products were absorbed by the market. A first reason for this situation is the request for high-quality products, in good condition and reliable. However, a second reason is also a general lack of information at the consumer level about the reliability and trustworthiness of processes performed by reuse centres. Additional warranties and information provided by reuse centres for their products could help to overcome the scepticism of some consumers. The adoption of specific labelling schemes could also support the development of this market (e.g. labels developed according to the requirements of prEN 50614).

The report also introduces a new method for the environmental assessment of the reuse of products. The tool, similarly to the one used for the durability analysis, has its foundations in life cycle assessment results and is applied to the same case studies introduced in the first chapter. Three main scenarios were defined, depending on whether the length of the first life of the case-study product before the reuse is: (1) relatively short, (2) intermediate or (3) equal to the product average lifetime. The analysis of the reuse of a WM proved that there are high or very high benefits for the large majority of the considered impacts when the WM derives from a relatively short first life (reuse situations 1 and 2). In situation 3, where the product was supposed to have a full first life, the benefits of reuse are dependent on such factors as the length of the second life, the potential drop in efficiency of the product and the efficiency of the replacement product. However, even in reuse situation 3 benefits were shown for the majority of impact categories and scenarios. Similar results have been observed for the DW case study. However, it is highlighted that the reuse of DW generally implies lower environmental benefits compared to WM for all the impact categories considered. This can be related to the higher energy consumption of DW during the use phase. Therefore, the environmental assessment of the reuse of the DW is more influenced by the assumption on the energy efficiency of the new replacement product and by the potential decrease in energy efficiency during the operation.

Chapter 3: Analysis of the reparability of WM and DW

The third chapter starts with an analysis of the statistics of repair services conducted on WM and DW over the 2009-2015 period. Statistics have been derived from data by the repair centre Reparatur- und Service-Zentrum — R.U.S.Z. More than 11 000 datasets were collected, including information such as type of failure mode, repair actions, replacement of components, reasons not to repair and so forth. For each product group it was possible to understand which components (or failure modes) were more often diagnosed, what actions were taken, which parts had the highest likelihood of being repaired and which others led the device to be discarded. Concerning WM, the principal failure modes involved the electronics (14 % of cases), shock absorbers and bearings (13.8 %), doors (11.5 %), carbon brushes (9.7 %) and pumps (7.5 %). While the highest repair rates were observed for doors, carbon brushes and removal of foreign objects, the lowest rates (repaired devices over total diagnosed devices with a specific failure mode) were observed for bearings (24 %), drums and tubs (27 %), circulation pumps (33 %) and electronics (49 %). Regarding DW, recurring failures involved pumps (almost 24 % of cases), electronics (16.7 %), aquastop and valves (8.4 %), foreign objects (6.9 %) and doors (6.4 %). The lowest rates (repaired devices over total diagnosed devices with a specific failure mode) were, however, again observed for circulation pumps (46 %) and electronics (44 %). Generally, repairs were technically possible, however customers tended to turn down repair services when considered too expensive (about 76-78 % of unrepaired devices). In other cases, a lack of spare parts or an ineffective design for disassembly prevented technicians from operating on the device. This analysis allowed the identification of aspects (and strategies) that are relevant for the improvement of product 'reparability' (meaning the ability of the product to be repaired). This also includes the attitudes of consumers that could cause certain failures of the products, or product design aspects that facilitate (or hamper) repair.

Final recommendations

Finally, the results and information provided in the three main chapters have been summarised in a series of concluding remarks and recommendations, which could help the policy discussion among stakeholders for the development of concrete measures for products. Concerning the improvement of the durability of WM and DW, the most straightforward strategy would imply the setting of minimum lifetime requirements, namely the average expected lifetime or the average number of washing cycles. However, no standard has been identified to measure the durability of these product groups. Specific standards for endurance tests are available for the testing of certain components of the machines. However, it is recognised that the lifetime of product components is not necessarily linked to the lifetime of the products, nor do these tests reflect the effective stresses occurring during the product's operation. Further research is definitely needed in this area. The durability of WMs and DWs could currently be promoted by the provision in the user manual of relevant information for the durability of products. For example, a dedicated section on the 'Durability of the product' could be inserted, including all relevant information about the proper use and maintenance of the products and the risks associated with incorrect use.

The statistical analysis of WM and DW failure modes could be used to focus attention on the product design in order to reduce these failure modes and facilitate product repair. A possible strategy for reparability would be the improvement of the design for disassembly of the devices in order to facilitate access, disassembly and the repair/replacement of specific components for WMs (e.g. shock absorbers, electronics, door handles, carbon brushes, circulation pumps and drain pumps) and DWs (e.g. circulation pumps and drain pumps, electronics, aquastop, handles, hoses, drain systems and inlet hoses, dispensers). Moreover, it is recommended that manufacturers facilitate the availability of spare parts. For example, manufacturers could provide information in the user manuals and on their own website on how these spare parts can be procured. The use of dedicated platforms to provide information about the availability of spare parts and their procurement should be also encouraged. Additional strategies to promote reparability could include: the design of products for 'ease of disassembly', to be assessed by metrics specifically developed for this purpose[3]; the promotion of labels awarded to products that are designed for easy repair (e.g. the label based on the standard ONR 192102).

Recommendations on the reparability of products would also facilitate potential reuse. In addition, in order to promote the reuse of WM and DW, reuse centres and professional repairers should be provided with relevant information, such as: the product's exploded diagram with a clear list of the referenced parts; wiring diagrams and connection diagrams; a list of test/diagnosis programs and error codes and, for each potential failure, the suggested technical action to be undertaken. Moreover, reuse centres and professional repairers should have access to tools and systems that allow them to re-program electronic components and erase error codes after the repair services.

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[3] For examples of metric to assess the ease of disassembly, see Vanegas et al. (2016) (https://ec.europa.eu/jrc/en/publication/study-method-assess-ease-disassembly-electrical-and-electronic-equipment-method-development-and?search access July 2016)

Additional strategies to facilitate the reuse of WM and DW could include: the provision of additional guarantees for reused products; the promotion of information campaigns to illustrate the economic, environmental and social benefits of reusing these products; the promotion of specific marking for the quality of reused products. Finally, it is also crucial that products discarded by users, but still having a certain potential for reuse, are not damaged during the collection phase. Reuse centres would benefit from having access to discarded products at an early stage of their collection. This access should be facilitated by either collection schemes, municipalities or other operators (such as retailers).

Introduction

This report has been developed within the project 'Technical support for environmental footprinting, material efficiency in product policy and the European Platform on LCA' (2013-2016) funded by the Directorate-General for the Environment. It aims to address relevant topics in terms of material efficiency, such as durability, reusability and reparability, for two product groups: washing machines and dishwashers.

The assessment of material efficiency aspects such as durability, repair and reuse for energy-related products (ErP) has been the subject of a number of recent studies. The importance of such aspects in policy has recently been reiterated by the EU action plan for the circular economy (European Commission, 2015), especially in its section concerning consumption. Durability as a material efficiency aspect was addressed by the European Commission by means of a recent report published by Ricardo-AEA (2015). The purpose of the study was to identify two priority products (refrigerators and ovens) and to develop a methodology for measuring their performance in terms of durability. According to Ricardo-AEA (2015), 'in circular economy terms, maintaining the first life use of a product is, in principle, the best approach to closing resource loops since any form of refurbishment, remanufacture, reprocessing or recycling necessarily requires an injection of additional resources and potentially a degrading of the product functionality or material value. Indeed, extended first use lifetimes are only bettered by removing the need for a product or service completely.' The life cycle environmental implications of requiring more durable devices were analysed: extending the lifetime from 10 to 15 years can lead to environmental life cycle benefits in those impact categories whose contribution depends mainly on the production phase, while for the impact categories mainly dependent from the energy consumption during the use phase, extending the durability of the product does not lead to significant environmental benefits. Ricardo-AEA (2015) also identified areas of the design phase of the two devices that could be potential targets for material efficiency requirements, such as door seals, lamps, thermostats, electronic controls and drainage channels (for refrigerating appliances).

Another study conducted by Prakash et al. (2016) addressed durability through an investigation of the material and functional obsolescence of energy-related products. According to the authors, the first useful service life of most of the studied product groups has decreased over recent years. Nevertheless, an increasing share of appliances are replaced or disposed before they reach an average first useful service life or age of 5 years. More than 10 % of the washing machines disposed at municipal collection points or recycling centres in 2013 were just 5 years old or less. This percentage was 6 % in 2004. In 69 % of cases a defect was the reason for disposing of a device, while in 10 % of cases the washing machines were replaced because they were not sufficiently efficient.

Also, the repair and maintenance of products has great potential to contribute to material efficiency in the context of the circular economy (Benton et al., 2015). According to Ricardo-AEA (2015), the repair of a product can bring potential benefits in terms of material and economic efficiency, but the impact of any replacement product potentially being more energy efficient must be considered; nevertheless, repairs occur in response to unplanned events, and as such are particularly difficult to anticipate and to account for in life cycle calculations.

A recent report focused on the socioeconomic impacts of increased reparability of products has been released by Deloitte (2016). The report presented a series of case studies based on the possible reparability requirements of different product groups, among them washing machines and dishwashers. Reparability requirements were therefore analysed and grouped based on the type of requirement: (1) requirements on information provision (generic ecodesign requirements for manufacturers to provide users and/or repairers with necessary information about reparability); (2) requirements on product design (to facilitate dismantling, diagnosis, access to critical components, repair, etc.); and (3) requirements on the provision of services (extended commercial guarantee, replacement parts). Deloitte (2016) concluded that the environmental impacts of different repair measures were neutral to positive, but with some clear gains in resources. The report also classified the variety of reasons why some goods are replaced instead of repaired into three main categories: technical barriers (such as incompatibilities with new technologies, lack of spare parts, software updates or repair information, etc.), economic barriers (tailored repair services can have a higher cost than mass production of new products) and legal barriers (security standards, patents and the policy objectives on recycling may not facilitate the choice of repair).

Study about the environmental assessment of the durability of washing machines and dishwasher have been also carried out by the Joint Research Centre — Sustainable Resources Directorate, in Ardente et al. (2012) and Ardente and Talens Peiró (2015). Those analyses concluded that extending the lifetime of the two devices was environmentally beneficial in the large majority of considered scenarios, especially for those impact categories that are not largely influenced by the consumption of energy during operation.

As the European Commission recently launched the revision of the ecodesign and energy label implementing measures for the product groups 'household washing machines and washer-dryers' and 'household dishwashers' (JRC, 2016a, 2016b), new reference products have been identified for the two product groups and a new data collection was performed to model the life cycle of the devices (relevant changes relate to the bill of materials (BoM) and the parameters of the use-phase scenarios). Building on the policy commitments of the EU action plan for the circular economy, there is a need to analyse the durability, reusability and reparability performances of these product groups, and this is the aim of this report.

The present report aims at updating previous studies conducted by the same JRC authors, referring to the base-case WM and DW products as identified by the ongoing preparatory studies. Furthermore, this work also enlarges the scope of the analysis, including new investigation and methodological developments and application to case studies concerning repair and reuse. Information provided by repair and reuse centres has been used to identify hotspots and potential barriers for product reuse. Finally, the study provides details on recurrent failure modes of DW and WM, ease of repair and the main obstacles to repairing a device.

Chapter 1

1. Durability analysis

The present chapter is devoted to the environmental assessment of the durability of two product groups: washing machines (WMs) and dishwashers (DWs). The study was conducted by means of durability indexes developed within the resource efficiency assessment of products (REAPro) method, as introduced by Ardente et al. (2012) and successively implemented by Bobba et al. (2015). The method is based on a life cycle approach and aims at analysing the environmental assessment of different lifetimes of energy-using products.

The starting point for the present durability assessment includes the revision of the life cycle assessment (LCA) study of representative WM and DW base cases. The results are then interpreted and compared to previous studies carried out by the JRC to assess the main changes in the products' composition and the related environmental impacts. Finally, durability index trends are calculated according to the previously mentioned methodology and shown for relevant indicators.

1.1. Introduction

In their first application of the methodology Ardente et al. (2012) observed that extending a washing machine's lifetime can bring potential environmental benefits; in the case of a 'low repairing' scenario[4] (LRS) during the useful lifetime of the device, and assuming postponement of the replacement with a 10 % more energy-efficient device, a 4-year lifetime extension could reduce global warming potential by 3-5.5 %[5], and the reduction of abiotic depletion potential (elements) could reach values of 23-24 %, regardless of the energy efficiency of the replacement product.

In a more recent work, Ardente and Talens Peiró (2015) applied the analysis of durability to the DW product group. Also in this case it is possible to observe potential environmental benefits thanks to lifetime extension; in the case of an LRS[6], and assuming postponement of the replacement with a 15 % more energy-efficient device, the lifetime extension could reduce abiotic depletion by 27 % and ecotoxicity and freshwater eutrophication by about 20 %, while other environmental impact categories see a smaller, though relevant, reduction (by 1-3 %).

These two reports were mainly based on input data derived from a preparatory study from 2007, especially concerning the consumption of energy in the use phase and the BoM of base-case products (ISIS, 2007). However, the ecodesign requirements for WMs and DWs are currently under revision, including a revision of data and calculations, objectives of the ongoing preparatory studies (JRC, 2016a, 2016b).

As one of the tasks of the present project 'Technical support for environmental footprinting, material efficiency in product policy and the European Platform on LCA', the

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[4] 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, such as the porthole).

[5] Two washing machine case studies were analysed, namely WM1 and WM2.

[6] 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, such as the pipes or seals).

JRC decided to revise the environmental assessment of durability of WMs and DWs, to be aligned with the revision of preparatory studies.

The present chapter is therefore divided into three main parts:

- a common methodological discussion of the applied method for the environmental assessment of durability, starting with the description of the system boundaries of the life cycle assessment studies;
- a section dedicated to the LCA and durability analysis of the WM product group;
- a section dedicated to the LCA and durability analysis of the DW product group.

1.2. Methodology

1.2.1. Life cycle assessment

The subject of the analysis consists of one representative device for each selected product group. The chapter is therefore divided into two main case studies.

- The household washing machine base case, an electrical appliance for the cleaning and rinsing of textiles using water which may also have a means of extracting excess water from the textiles (EN 60456, 2011). The objective of the analysis, instead, is to perform a cradle-to-grave LCA of the WM base case, considering the overall life cycle, including the use of detergents and the final treatment of waste water (see Section 1.3).
- The household dishwasher base case, an electrical device which cleans, rinses and dries dishware, glassware, cutlery, and, in some cases, cooking utensils by chemical, mechanical, thermal, and electric means (a dishwasher may or may not have a specific drying operation at the end of the program) (EN 50242, 2008). The objective of the analysis, similarly to the previous case study, is to perform a cradle-to-grave LCA of the DW base case, considering the overall life cycle, including the use of detergents, salt and rinsing agents, as well as the final treatment of waste water (see Section 1.4).

The main life cycle phases considered for both LCA and the durability analyses are summarised hereinafter.

- Production ‘P’: consists of the device (WM or DW) production model, including raw-material extraction, refinement and processing, component production, device assembly, packaging and final delivery.
- Use phase ‘U’: consists of the device (WM or DW) use-phase model, including the consumption of electricity, water, detergents and auxiliary materials during the washing cycles.
- Repair ‘R’: includes the impacts related to repairs that allow the operational life of the product to be prolonged; repairs are supposed to occur during the use phase.
- End of life ‘E’: consists of the device (WM or DW) end-of-life model, including transport and impact of waste treatment in a waste electrical and electronic equipment (WEEE) recycling plant. According to Ardente and Mathieux (2014), potential credits related to the recycling and recovery of materials have not been considered in the analysis in order to avoid the overlapping of the environmental benefits of both recyclability and durability.

The LCA results shown in the following section refer to the functional unit of one device (one household WM base case or one household DW base case).

1.2.2. Environmental impact categories

The impact categories used for the analysis refer to the midpoint indicators as recommended by the ILCD framework for life cycle impact assessment (LCIA) models and indicators (ILCD handbook — JRC, 2010). Concerning the abiotic depletion potential, this has been subdivided into 'fossil' and 'element' components according to CML (2001), since the ILCD method does not differentiate among mineral, fossils and renewables sources depletion. The following impact categories listed by ILCD have been used:

- Acidification, measured in mole of H^+ equivalent.
- Climate change, measured by the global warming potential (GWP) as kg of CO_2 equivalent.
- Ecotoxicity freshwater, measured in CTUe.
- Eutrophication freshwater, measured in kg P equivalent.
- Eutrophication marine, measured in kg N equivalent.
- Eutrophication terrestrial, measured in mole of N equivalent.
- Human toxicity, cancer effects, measured in CTUh.
- Human toxicity, non-cancer effects, measured in CTUh.
- Ionising radiation, human health, measured in kBq U-235 equivalent.
- Ozone depletion, measured in kg CFC-11 equivalent.
- Particulate matter, also known as respiratory inorganics, measured in kg PM 2.5 equivalent.
- Photochemical ozone formation, measured in kg NMVOC equivalent.
- Resource depletion water, measured in m^3 equivalent.
- Abiotic depletion (elements)[7], measured in kg Sb equivalent.
- Abiotic depletion (fossil)[8], measured in MJ.

These impacts categories are, however, not fully consistent with those used in the previous studies by the JRC on durability. In particular, the previous studies used different indicators and units of measurement for the following impact categories.

- Acidification, measured in previous studies in kg SO_2 equivalent.
- Ecotoxicity, measured in PAF m^3/day.
- Eutrophication terrestrial, measured as m^2 UES.
- Human toxicity, cancer and non-cancer effects, measured in cases.
- Ionising radiation, human health, measured in kg U-235 equivalent.
- Particulate matter formation, also called respiratory effects, measured in kg PM 10 equivalent.
- Resource depletion water, not available.

Where possible, the present LCA base cases were additionally assessed using the CML 2001 impact assessment methods to be consistent with previous analyses. Further details are given in the following sections.

1.2.3. Durability analysis

As previously mentioned, the environmental assessment of the durability of washing machines and dishwashers is based on the method initially developed by Ardente et al. (2012) and recently revised and modified by Bobba et al. (2015). The method consists of assessing environmental benefits (or impacts) through durability indexes. For the sake

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[7] CML 2001 Impact Assessment Method, Center of Environmental Science of Leiden University.

[8] CML 2001 Impact Assessment Method, Center of Environmental Science of Leiden University.

of simplicity, we are reporting the updated version of the method hereinafter, assuming the configuration of Figure 1.1 and the following parameters as initial conditions.

- A identifies the analysed product (WM of DW) base case, with a lifetime T_A.
- A' identifies a more durable product (WM of DW) base case, with a lifetime $T_A + X$.
- B identifies the substituting product.
- Base scenario: product (A) is substituted by product (B) after operating time T_A.
- Durability scenario: product (A') is substituted by product (B) after operating time T_A and time extension X.

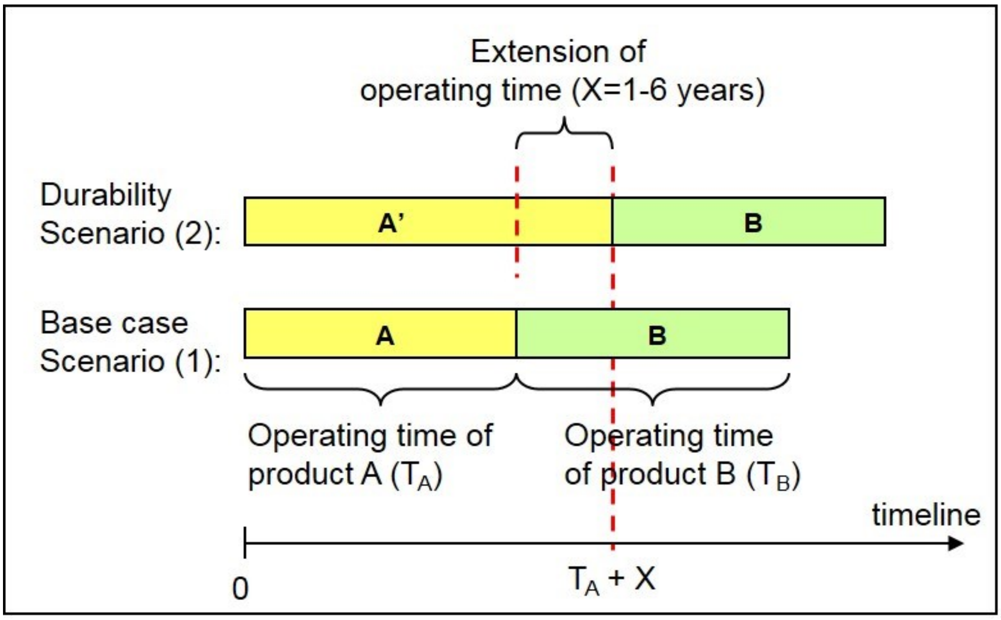

Figure 1.1. Scenarios for durability analysis (Ardente et al., 2012; Bobba et al., 2015)

Therefore, given a standard product (A), which, at the end of its operating life, is substituted by a new product B, the durability index D, referred to a generic impact category n, can be calculated as follows:

$$D_n = \frac{\frac{(\gamma_n - \alpha_n)\cdot P_{A,n}}{T}\cdot X + \frac{E_n}{T}\cdot X - (1-\delta)\cdot u_{ELA,n}\cdot X - R_{A,n}}{P_{A,n} + u_{A,n}\cdot T + E_n}\cdot 100 \qquad (1)$$

Where:

- D_n is the durability index for the impact category n (%);
- T is the average operating time of product (A) and (B) (year), assumed to be the same ($T_A = T_B$);
- X is the extension of the operating time of product (A) (year);
- $P_{A,n}$ is the environmental impact for category n, for the production of product (A) (unit); includes the extraction of raw materials, processing and manufacturing;

- γ_n represents the variation of the environmental impact due to the manufacturing of newer products and in this case consists of the fraction between $P_{B,n}$ and $P_{A,n}$ (%); $P_{B,n}$ is the environmental impact for category n, for the production of product (B) (unit); includes the extraction of raw materials, processing and manufacturing;
- α_n represents the incremental environmental impact necessary to make product (A) more durable (i.e. (A′)) and in this case consists of the fraction between ($P'_{A,n} - P_{A,n}$) and $P_{A,n}$ (%);
- E_n is the environmental impact for category n for the EoL treatments of products (A) and (B) (unit), assumed to be the same ($E_A = E_B$)[9];
- δ represents the energy-efficiency improvement of new product (B) substituting product (A), and in this case consists of the fraction between the energy consumption during the use phase of product (B) and the energy consumption during the use phase of product (A) (%);
- $u_{A,n}$ is the environmental impact per unit of time for category n for the use of product (A), including impacts due to the consumption of electricity, water, detergents and auxiliary materials (units/year);
- $u_{ELA,n}$ is the environmental impact per unit of time for category n for the energy consumption of product (A), including only impacts due to the consumption of electricity (units/year);
- $R_{A,n}$ is the environmental impact per unit of time for category n for additional treatments (e.g. repair) necessary during the operating time of product (A) (unit).

The denominator of the Formula (1) accounts for the whole life cycle impact of the product (A), while the numerator includes the difference between the environmental impacts of the base-case scenario (number 1 in Figure 1.1: product (A) replaced by a new product (B)) and the impacts of the durability scenario (number 2 in Figure 1.1: operating time of the product (A) extended by a certain number of years "X"). In summary, the numerator of the formula represents the difference of the environmental impacts between a more durable product compared to a product with an average lifetime. Finally, the durability index[10] expresses (in percentage) how relevant are the benefits of a more durable product compared to the lifecycle impacts of the product itself. A negative value of the numerator (and consequently of the overall durability index) indicates that the extension of the operating time of the product is not environmentally convenient compared to its replacement with a new one.

The formula takes into account the potential progress of new technologies; in particular, newer products with higher energy efficiency, as it is *de facto* assumed that prolonging the lifetime of standard product (A) is always environmentally convenient if its environmental impact for the use is lower than the environmental impact for the use of newer product (B), as stated by Ardente and Mathieux (2014). The same authors assert that the manufacturing technological progress is not accompanied by the same progress for end-of-life treatments, assuming that the environmental impacts at the end of life of both products are the same. It is also assumed that the two products (A) and (B) have the same operating time expectancy (T).

The new parameter α was introduced by Bobba et al. (2015) for a durability assessment of vacuum cleaners. According to the authors, this leads to a more comprehensive scenario where additional impacts necessary to make product (A) more durable are taken into account. Practical examples of additional impacts necessary improve durability

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[9] Potential benefits derived by recycling or incineration are not included (see section 1.2.1).

[10] For additional details and discussions on the calculation of the durability index and its interpretation, see (Ardente et al., 2012; Bobba et al., 2015).

can be represented by (but not necessarily limited to) higher quality of materials during the manufacturing process. In the vacuum cleaner case study, a percentage of + 5 % was assigned to abiotic depletion potential, + 7 % for human toxicity and + 3 % for other impact categories. The same values could not be used for the present case studies as the product groups are not similar. Different hypotheses were considered for the analysis of WM and DW, and will be explained in the following sections.

Durability indices D_n will be graphically represented using charts specifically built for each impact category. Charts consist of Cartesian coordinate systems with δ on the X-axis and D_n on the Y-axis. Figure 1.2 is an artificial example of data visualisation, in which:

- for $D_n > 0$, prolonging the lifetime of the standard product (A) is environmentally more convenient than upgrading to a newer, more efficient product (B) — in Figure 1.2, this happens when $\delta > 85$ %;
- for $D_n \leq 0$, prolonging the lifetime of the standard product (A) is not environmentally more convenient than upgrading to a newer, more efficient product (B) — in Figure 1.2, this happens when $\delta \leq 85$ %.

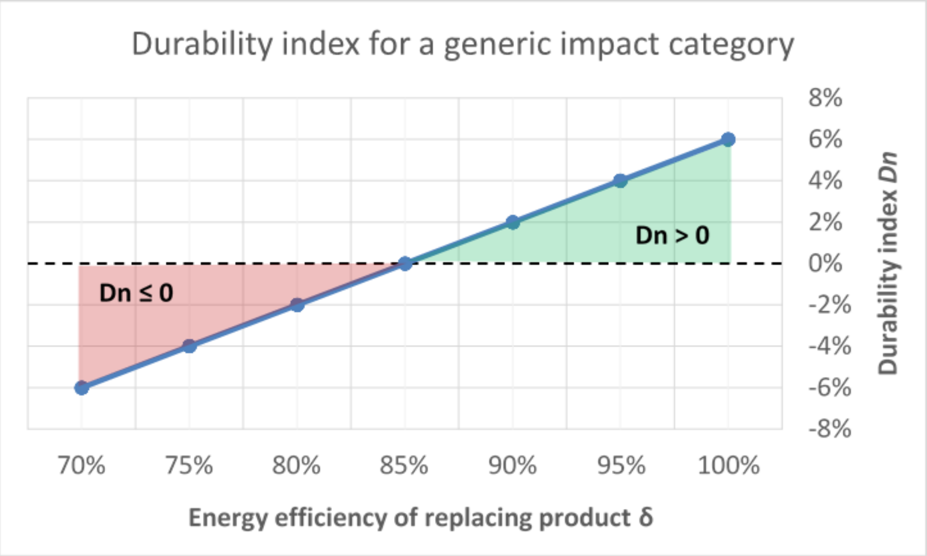

Figure 1.2. Generic data visualisation for the durability index

1.3. Durability analysis of washing machines

1.3.1. Presentation of the case study: WM base case

The case study consists of a WM representing an exemplar EU product, as several appliances of similar functionalities have been compiled to obtain a final base case, called ‘WM base case’ hereinafter.

The selected WM base case corresponds to the product analysed in the revision of the preparatory study on WM (JRC, 2016b) and assessed by means of the methodology for the ecodesign of energy-related products (MEErP) (EcoReport, 2014). The base case refers to a household washing machine with a nominal rated capacity of 7 kg. The main features and key data are summarised in Table 1.1. Values of energy and water consumption have no direct correspondence with energy-label classes, as real-life conditions were considered to estimate the two figures.

Table 1.1. Main characteristics and key data for the present WM base case (modified from (JRC, 2016b), based on private communications with the authors of the preparatory study)

Present WM base-case features		
Nominal rated capacity	7	kg
Washing performance class	A	-
Spin drying performance class	B	-
Use rate	220	cycles/year
Energy consumption [11]	147.8	kWh/year
Water consumption [10]	10 318	l/year
Detergent consumption (solid)	75	g/cycle
Detergent consumption (liquid)	75	ml/cycle
Lifetime	12.5	years

1.3.2. Goal and definition of scope

The goal of the environmental analysis consists of updating the LCA study on a household washing machine representative base case and updating the durability analysis conducted by Ardente et al. (2012).

The functional unit used for this analysis consists of one WM, with a lifetime expectancy of 12.5 years, as presented in Section 1.3.1.

The scope of the analysis consists of the WM life cycle, considering a cradle-to-grave system boundary. As defined in Section 1.2.1, production phase (P), use phase (U), repair (R) and end of life (E) are considered. The impacts of detergents, including end-of-life treatment and depuration of waste water in a waste water treatment plant, are included in the system boundaries and allocated to the use phase.

The end of life (E) includes the activities (manual and mechanical treatments) in a WEEE recycling plant. Further treatments (waste streams transport, incineration, landfilling, etc.) are considered out of scope. Environmental credits due to recovery of materials or energy are not considered in this assessment (Section 1.2.1).

1.3.3. Life cycle inventory

1.3.3.1. Data collection

The data collection for the BoM is based on the revision of the preparatory study (JRC, 2016b) developed thanks to the input provided by manufacturers. The detailed BoM of the WM base case is specified in Table A.1 of Annex A, while in Table 1.2 we show an aggregated BoM using five material categories related to the material types used for the device (plastics, ferrous metals, non-ferrous metals, electronics, other materials) and an additional category for packaging.

Table 1.2 presents the BoMs of the previous case studies, named WM1 and WM2 by Ardente et al. (2012). The two household washing machines WM1 and WM2 were representative of the medium–low-price and high-price segments of the market, both of them with nominal rated capacity of 5 kg. It is interesting to note that the present base case considers a device with a higher capacity and lower mass.

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[11] Consumptions in real-life conditions estimated through a survey among users, conducted in March-April 2015 across Europe (JRC, 2016b).

Table 1.2. Bill of materials of the present WM base case as described by JRC (2016b) and the two case studies WM1 and WM2 used by Ardente et al. (2012)

Material categories	Present WM base case *(mass in g)*	WM1 (2012) *(mass in g)*	WM2 (2012) *(mass in g)*
Plastics	11 796	12 685	6 810
Metals (ferrous)	28 527	25 624	73 513
Metals (non-ferrous)	4 082	3 701	5 111
Electronics	225	362	1 929
Other materials	22 056	29 371	9 689
Packaging	2 916	n/a[12]	n/a
Total	**69 602**	**71 743**	**97 052**

A direct comparison of the different case-studies is not consistent since the machines had different capacity and, therefore different functions. However, observing the three BoMs it was noticed that the material distribution of these products is similar. The main difference in the material distribution is driven by the type of counterweight used: both the present WM base case and WM1 have a concrete counterweight (20.2 kg in the first case, 22.7 kg in the second case), while WM2 used cast iron (28.8 kg, including other cast iron parts). When compared to WM1 and WM2, the present WM base case has a smaller mass of electronic components (– 38 % compared to WM1 and – 88 % compared to WM2). If compared to WM1 (same counterweight type and similar mass) it is possible to appreciate a reduction in plastics (– 7 %) and an increase in metals (+ 11 % for ferrous metals and + 10 % for non-ferrous metals).

The data collection for the other phases of the WM life cycle was principally based on the current preparatory study (JRC, 2016b). However, a few deviations were adopted in order to have a system boundary comparable to Ardente et al. (2012), needed for the durability analysis, and also to adapt the input and output of data to the commercial LCA software used for modelling. Table 1.3 summarises the main assumptions concerning the WM life cycle.

Table 1.3. Life cycle phases and relevant aspects concerning the WM life cycle

Life cycle-relevant aspect	**Main assumptions**
Transport of materials to the manufacturing plant	For each material category, an average transport of 300 km by lorry was added, representing the shipping of the material to the point of processing
Plastic processing	An average injection moulding operation was used to represent the processing of plastic components
Ferrous metal processing	An average sheet stamping and bending operation was used to represent the processing of ferrous components

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[12] Not available.

Life cycle-relevant aspect	**Main assumptions**
Non-ferrous metal processing	An average die-casting operation was used to represent the processing of non-ferrous components
Electronics	The material category 'Electronics' was assumed to be constituted by a printed circuit board
Assembly phase	Both power and thermal energy consumption were estimated for one device according to ISIS (2007): electricity consumption 28.98 kWh; thermal energy 14.79 kWh
Transport and distribution of the device to the final user	The transport and distribution of the product to the final consumer was modelled according to the MEErP background data, therefore sea transport (12 000 km), rail transport (100 km) and transport by lorry (1 660 km) (Kemna, 2011)
Use phase — energy consumption	A lifetime of 12.5 years and an energy consumption in real-life conditions of 0.672 kWh/cycle were considered; the overall energy use was assumed to be equal to 1.85 MWh per life cycle and modelled using the low-voltage European electricity mix
Use phase — water consumption	A water consumption of 46.9 litres/cycle was considered, and the total water consumption was assumed to be equal to 129 m^3 per life cycle; the same amount of water is assumed to be drained as waste water
Use phase — detergents	A detergent consumption of 75 g/cycle was considered. Midpoint impacts from (Golsteijn et al., 2015)
Repair	Repair was modelled with an amount of spare parts equal to 1 % of the WM base-case mass; spare parts are delivered to the final user with the average transport and distribution described for the device; no additional energy is supposed to be used for maintenance

Life cycle-relevant aspect	**Main assumptions**
Transport of the device to the end-of-life facility	An average transport of 100 km by lorry was added, representing the delivery of the device to the recycling plant
End of life	The WM base case and the spare parts are assumed to be treated by a WEEE recycling plant (Ardente and Mathieux, 2014b); waste packaging is assumed to be destined for a different stream and recycled
End of life processing	The WM base case and the spare parts are assumed to be processed by a combination of manual and mechanical treatments (see Ardente and Talens Peiró, 2015); the overall energy use was assumed to be equal to 0.066 kWh/kg of WEEE [13] and modelled using the medium-voltage European electricity mix

1.3.3.2. LCI background data

The commercial software GaBi was used to build the LCA model and as a database for processes (Professional Database and Extension Database XI: Electronics). Specific processes not available within GaBi databases were retrieved from ecoinvent.

The LCA model was built considering:

- average road transport by lorry, 22 t;
- average rail transport by train, 726 t payload capacity;
- average sea transport by fuel-oil-driven cargo vessel, 27 500 t payload capacity;
- the European electricity mix, medium voltage, was used for manufacturing and EoL operations;
- the European electricity mix, low voltage, was adopted for the use-phase operation.

The category 'Electronics' was modelled through GaBi datasets using the BoM of a Pb-free printed circuit board, available in the ecoinvent database[14]. The BoM is detailed in Table A.3 of Annex A.

Regarding the assembly phase, the following assumptions were considered.

- Electricity consumption modelled as European electricity mix, medium voltage.
- Thermal energy modelled as energy from natural gas combustion.

Regarding the detergent, aggregate midpoint results for the life cycle of a compact powder laundry detergent were retrieved from Golsteijn et al. (2015)[15]. The reference flow of 81.5 g initially used by Golsteijn et al. (2015) was then normalised to 75 g, used in the present case study. However, it is worth to note that detergents nowadays are

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[13] Treatment of waste electric and electronic equipment, shredding, GLO, ecoinvent operation.

[14] Printed wiring board production, surface mounted, unspecified, Pb free.

[15] The life cycle includes the impacts of ingredients, formulation, packaging, transport and end of life.

going to contain less and less phosphorous, implying a lower impact of the use phase on the eutrophication impact category (JRC, 2016b). Environmental results are summarised in Table A.4 of Annex A.

Regarding the packaging, its waste flow is considered to occur during the WM use phase.

1.3.4. Life cycle impact assessment results

Results of the LCIA phase are summarised in Table 1.4. Figures are referred to the unit of one WM and totals are divided into the main phases: production, use phase and repair, end of life.

Table 1.4. Life cycle impact assessment. Results referred to the functional unit of one WM base case. P = production, assembly, distribution; U+R = use phase and repair; E = end of life

Impact category	**Totals**	**P**	**U+R**	**E**
Acidification (mole of H+ eq.)	**5.37E+00**	2.52E+00	2.84E+00	8.49E-03
Climate change (GWP) (kg CO_2 equiv.)	**1.65E+03**	2.67E+02	1.39E+03	1.85E+00
Ecotoxicity freshwater (CTUe)	**4.49E+02**	4.09E+02	4.01E+01	2.90E-01
Eutrophication freshwater (kg P eq.)	**3.74E-01**	1.14E-03	3.73E-01	3.43E-06
Eutrophication marine (kg N equiv.)	**5.62E-01**	2.36E-02	5.38E-01	8.29E-05
Eutrophication terrestrial (mole of N eq.)	**9.60E+00**	3.87E+00	5.70E+00	2.45E-02
Human toxicity, cancer effects (CTUh)	**5.97E-06**	4.79E-06	1.16E-06	2.56E-08
Human toxicity, non-cancer effects (CTUh)	**1.10E-04**	8.54E-05	2.46E-05	3.80E-08
Ionising radiation, human health (kBq U235 eq.)	**3.84E+02**	1.79E+01	3.65E+02	5.26E-01
Ozone depletion (kg CFC-11 eq.)	**5.98E-05**	4.27E-06	5.55E-05	1.86E-09
Particulate matter (kg PM2.5 equiv.)	**3.59E-01**	2.03E-01	1.56E-01	3.74E-04
Photochemical ozone formation (kg NMVOC)	**4.28E+00**	1.09E+00	3.19E+00	6.37E-03
Resource depletion water (m^3 eq.)	**4.09E+01**	1.08E+00	3.98E+01	3.05E-02
Abiotic depletion (ADP fossil) (MJ)	**1.37E+04**	3.46E+03	1.02E+04	2.22E+01
Abiotic depletion (ADP elements) (kg Sb equiv.)	**3.22E-02**	3.16E-02	6.31E-04	5.72E-07

Recycling, as well as other recovery techniques, contributes to the production of secondary raw materials and to avoid the extraction of primary raw materials and the production of virgin materials; even though this is generally modelled as an avoided impact (therefore a credit, expressed as a negative number), the benefits of material recovery are out of the scope of this LCA model.

Table 1.5. Life cycle impact assessment — contributors to results. Percentages referred to the functional unit of one WM base case. P = production, assembly, distribution; U+R = use phase and repair; E = end of life

Impact category	**Totals**	**P**	**U+R**	**E**
Acidification (mole of H+ eq.)	100.0 %	47.0 %	52.9 %	0.2 %
Climate change (GWP) (kg CO_2 equiv.)	100.0 %	16.2 %	83.7 %	0.1 %
Ecotoxicity freshwater (CTUe)	100.0 %	91.0 %	8.9 %	0.1 %
Eutrophication freshwater (kg P eq.)	100.0 %	0.3 %	99.7 %	0.0 %
Eutrophication marine (kg N equiv.)	100.0 %	4.2 %	95.8 %	0.0 %
Eutrophication terrestrial (mole of N eq.)	100.0 %	40.4 %	59.4 %	0.3 %
Human toxicity, cancer effects (CTUh)	100.0 %	80.2 %	19.4 %	0.4 %
Human toxicity, non-cancer effects (CTUh)	100.0 %	77.6 %	22.4 %	0.0 %
Ionising radiation, human health (kBq U235 eq.)	100.0 %	4.7 %	95.2 %	0.1 %
Ozone depletion (kg CFC-11 eq.)	100.0 %	7.1 %	92.9 %	0.0 %
Particulate matter (kg PM2.5 equiv.)	100.0 %	56.5 %	43.4 %	0.1 %
Photochemical ozone formation (kg NMVOC)	100.0 %	25.5 %	74.4 %	0.1 %
Resource depletion water (m^3 eq.)	100.0 %	2.6 %	97.3 %	0.1 %
Abiotic depletion (ADP fossil) (MJ)	100.0 %	25.3 %	74.5 %	0.2 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	100.0 %	98.0 %	2.0 %	0.0 %

1.3.5. Life cycle interpretation

Use and repair (U+R) and production (P) are the most relevant phases of the WM base case analysis. While the consumption of electricity during the operational life of the device is responsible for the majority of the environmental impacts, the production phase contributes to more than 50 % of the freshwater ecotoxicity, human toxicity (both cancer effects and non-cancer effects), particulate matter (PM2.5 eq.) and ADP elements.

A breakdown of the main contributors to the P and U+R phases is provided in this section, in Table 1.6 and Table 1.7.

Regarding the present WM base-case production phase, impacts are mainly due to the production of materials. Most of the environmental impacts of the production phase are dominated by the contribution of metals, including both ferrous and non-ferrous metals (e.g. 92.7 % of freshwater ecotoxicity, 98.1 % of ozone depletion, 88.2 % of human toxicity — non-cancer effects, 69.3 % of ADP elements); main contributors among metals are represented by the use of stainless steel and by the use of copper (in particular for ADP elements). Concerning electronic components, the impact categories with the highest contribution to results are the resource depletion of water (33.2 %) and particulate matter (31.4 %). For plastic components, the highest contribution to impacts concerns marine eutrophication (40.6 % of the overall production phase), mainly due to the use of fibre glass. The category 'Other' (which includes glass, concrete, packaging, assembly, transport and distribution) is important for terrestrial eutrophication (43.4 %) and photochemical ozone formation (40 %), in which transport and distribution are playing a key role.

Table 1.6. Life cycle impact assessment — contributors to results. Percentages referred to the P column, representing the impacts of the P phase (production, assembly, distribution) for the functional unit of one WM base case

Impact category	**P**	Plastics	Metals[16]	Electronic comp.	Other[17]
Acidification (mole of H+ eq.)	**2.52E+00**	5.7 %	51.1 %	20.1 %	23.2 %
Climate change (GWP) (kg CO_2 equiv.)	**2.67E+02**	11.5 %	47.8 %	25.3 %	15.4 %
Ecotoxicity freshwater (CTUe)	**4.09E+02**	1.1 %	92.7 %	5.0 %	1.2 %
Eutrophication freshwater (kg P eq.)	**1.14E-03**	8.0 %	62.9 %	24.0 %	5.0 %
Eutrophication marine (kg N equiv.)	**2.36E-02**	40.6 %	17.9 %	17.7 %	23.8 %
Eutrophication terrestrial (mole of N eq.)	**3.87E+00**	6.1 %	33.1 %	17.5 %	43.4 %
Human toxicity, cancer effects (CTUh)	**4.79E-06**	6.6 %	61.3 %	26.1 %	5.9 %
Human toxicity, non-cancer effects (CTUh)	**8.54E-05**	1.3 %	88.2 %	9.3 %	1.2 %
Ionising radiation, human health (kBq U235 eq.)	**1.79E+01**	20.5 %	39.5 %	19.0 %	21.0 %
Ozone depletion (kg CFC-11 eq.)	**4.27E-06**	0.5 %	98.1 %	0.4 %	1.0 %
Particulate matter (kg PM2.5 equiv.)	**2.03E-01**	17.0 %	35.2 %	31.4 %	16.3 %
Photochemical ozone formation (kg NMVOC)	**1.09E+00**	6.5 %	35.8 %	17.7 %	40.0 %
Resource depletion water (m^3 eq.)	**1.08E+00**	23.4 %	23.2 %	33.2 %	20.3 %
Abiotic depletion (ADP fossil) (MJ)	**3.46E+03**	18.3 %	40.7 %	25.4 %	15.6 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	**3.16E-02**	1.8 %	69.3 %	28.8 %	0.0 %

As previously stated, the U+R phase is mainly dominated by the electricity consumption during the useful operational life. The use of detergent, however, affects the majority of freshwater eutrophication (98.6 %), marine eutrophication (86.7 %) and ozone depletion (98.8 %), while photochemical ozone formation (52.5 %) and GWP (34.6 %) are influenced as well, but to a smaller extent. The use of low-content phosphorous could result in reduction of the freshwater eutrophication impact, up to 90% (JRC,

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[16] Includes ferrous and non-ferrous metals.

[17] Includes other materials (glass and concrete), packaging, assembly, transport and distribution.

2016b). We also noticed how the use of water is relevant for water resource depletion (54 %), while repair, consisting of the impact due to spare parts, plays a key role for abiotic depletion of elements (50.6 %) and contributes significantly to results for freshwater ecotoxicity, with 10.3 % of the column U+R.

Table 1.7. Life cycle impact assessment — contributors to results. Percentages referred to the U+R column, representing the impacts of the use phase and repair for the functional unit of one WM base case

Impact category	**U+R**	Electricity	Detergent	Water	Repair (R)
Acidification (mole of H+ eq.)	**2.84E+00**	94.3 %	0.0 %	4.8 %	0.9 %
Climate change (GWP) (kg CO_2 equiv.)	**1.39E+03**	62.0 %	34.6 %	3.3 %	0.2 %
Ecotoxicity freshwater (CTUe)	**4.01E+01**	60.1 %	0.0 %	29.6 %	10.3 %
Eutrophication freshwater (kg P eq.)	**3.73E-01**	0.5 %	98.6 %	0.9 %	0.0 %
Eutrophication marine (kg N equiv.)	**5.38E-01**	10.1 %	86.7 %	3.2 %	0.0 %
Eutrophication terrestrial (mole of N eq.)	**5.70E+00**	92.7 %	0.0 %	6.6 %	0.7 %
Human toxicity, cancer effects (CTUh)	**1.16E-06**	61.2 %	0.0 %	34.6 %	4.2 %
Human toxicity, non-cancer effects (CTUh)	**2.46E-05**	76.3 %	0.0 %	20.2 %	3.5 %
Ionising radiation, h. health (kBq U235 eq.)	**3.65E+02**	99.3 %	0.0 %	0.7 %	0.0 %
Ozone depletion (kg CFC-11 eq.)	**5.55E-05**	1.1 %	98.8 %	0.0 %	0.1 %
Particulate matter (kg PM2.5 equiv.)	**1.56E-01**	92.8 %	0.0 %	5.9 %	1.3 %
Photochemical ozone formation (kg NMVOC)	**3.19E+00**	44.1 %	52.5 %	3.0 %	0.3 %
Resource depletion water (m^3 eq.)	**3.98E+01**	23.7 %	22.3 %	54.0 %	0.0 %
Abiotic depletion (ADP fossil) (MJ)	**1.02E+04**	91.3 %	1.5 %	6.8 %	0.3 %
Abiotic depletion (ADP elements) (kg Sb eq.)	**6.31E-04**	44.4 %	0.0 %	5.0 %	50.6 %

1.3.6. Analysis of the results of different case-studies

The main features and key data of the present WM base case and case studies WM1 and WM2 used by Ardente et al. (2012) are summarised in Table 1.8. As mentioned in section 1.3.3.1, the current base case cannot be considered fully consistent with case studies WM1 and WM2, since the considered machines have different capacity and functions, and the previous study (Ardente et al, 2012) assumed different system boundaries. Differences between the present base case and the devices analysed by Ardente et al. (2012), include rated capacity, lifetime expectancy and use rate. Furthermore, Ardente et al. (2012) used a different impact assessment method, thus only a subset of environmental indicators could potentially be considered. Variability in the comparison of results is also due to the use of different LCA databases, which can influence the LCIA of systems; for instance, Ardente et al. (2012) considered an average GWP impact for the EU electricity mix of 0.590 kg CO_2 eq./kWh, whereas now the impact factor is 0.473 kg CO_2 eq./kWh.

It is important to highlight that even though the energy consumption per cycle has decreased (it used to be 0.76 kWh/cycle whereas it is now approximately 0.672 kWh/cycle), the yearly electricity consumption during the use phase has increased by 18 %, while water consumption has increased by about 51 % yearly. These two main changes are driven by a higher use rate, which moved from 175 cycles/year to 220 cycles/year (+ 26 %).

Table 1.8. Main characteristics and key data for the present WM base case and the case studies WM1 and WM2 used by Ardente et al. (2012)

Washing machine features		**Present WM base case**	**WM1 and WM2 (2012)**
Nominal rated capacity	kg	7	5
Use rate	cycles/year	220	175
Annual energy consumption	kWh/year	147.8	133
Annual water consumption	m^3/year	10.3	6.23
Lifetime	years	12.5	11.4

An evaluation, however, was made between the results of the current study and the results presented in the WM preparatory study (JRC, 2016b). In Figure 1.3 the results refer to one WM base case with a lifetime of 12.5 years. It is possible to identify a total GWP for the present WM base case that is 9 % higher than the result obtained with MEErP, which is mainly due to the use of a different database for LCI datasets and processes. Other indicators were not compared as the impact assessment method of the two tools (GaBi and MEErP) is different.

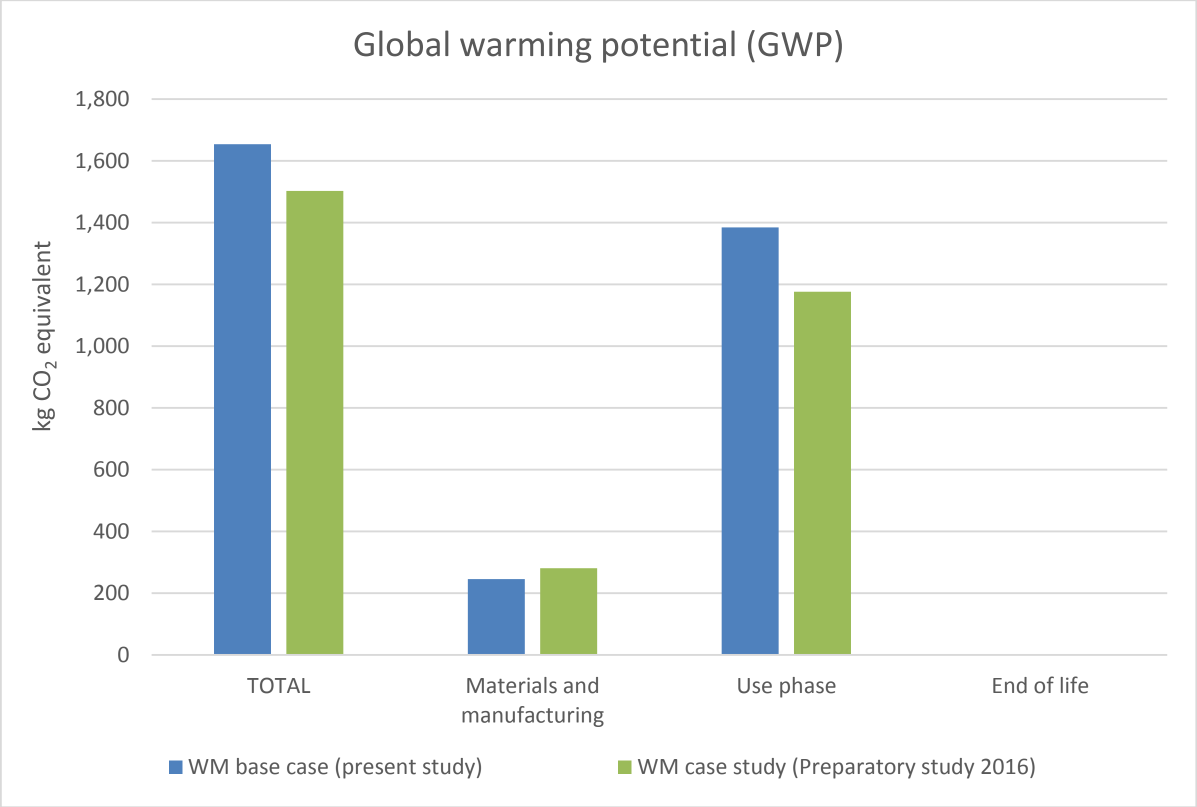

Figure 1.3. GWP comparison between two studies referred to washing machines. The functional unit consists of one 'WM base-case' washing machine with a lifetime of 12.5 years

1.3.7. Final remarks

The environmental analysis conducted on the WM base case aims at revising the former study on average EU products (Ardente et al., 2012). Overall, use and production are the most relevant phases of the WM life cycle. The use-phase impacts are mainly influenced by the energy consumption (for instance, GWP and ADP fossil), detergents (marine and freshwater eutrophication, ozone depletion potential) and spare parts used during the repair (ADP elements). On the other hand, the production phase is mainly affected by the use of metals (especially for ADP elements, GWP, ecotoxicity and human toxicity); the main contributors to these impacts originate from the use of stainless steel and copper.

Compared to the case studies WM1 and WM2 used by Ardente et al. (2012), a main difference is represented by the useful lifetime (12.5 years instead of 11.4) and the frequency of use (220 cycles/year instead of 175). This results in different impacts for the use phase, which are compensated for by the smaller amount of energy required for each cycle (0.672 kWh/cycle instead of 0.76) and the updated impact factors for energy use.

Considering the total GWP result obtained with MEErP, the present WM base case is 9 % higher, mainly due to the use of a different database for LCI datasets and processes.

1.3.8. Durability indexes for washing machines

Several figures and references for WMs' lifetimes are available in the literature. In a recent study, Prakash et al. (2015) stated that the service life for WMs is on average 11.9 years (first useful service life), in Germany, but varies between 9 and 20 years when several geographical areas (including countries outside Europe) are considered. Ardente et al. (2012) assumed an average lifetime of 11.4 years in order to assess the environmental impact of possible lifetime extensions (13.4 and 15.4 years). The lifetime considered for this device in the preparatory study on ecodesign requirements was equal to 12.5 years, and this value has been used as a reference for this study as well.

Table 1.9. Main characteristics and key data for the durability analysis

Characteristics	**Value**	**Unit**
Use rate	220	cycles/year
Annual energy consumption (in real-life conditions)	147.8	kWh/year
Lifetime (operating time **T**)	12.5	years
Operating time extension **X** (variable)	1-6	years
Energy consumption improvement **δ** (product (B) compared to (A))	70-100 %	
Manufacturing impact variation γ (product (B) compared to (A))	variable	
γ for GWP	75-125 %	
γ for ADP elements	150-200 %	
γ for freshwater eutrophication	75-125 %	
Incremental environmental impact to make A more durable (A') **α**	variable	
α for GWP	0-30 %	
α for ADP elements	0-60 %	
α for freshwater eutrophication	0-30 %	

Values of γ and α (see section 1.2.3) are generally affected by uncertainty, since these refer to potential newer replacing products compared to the product under analysis. The durability assessment method therefore adopts a wide range of variation of these parameters to explore different scenarios. In particular, the analysis of different LCA studies in different years can help to derive information about the evolution of the impacts for the considered product group, including impacts of more durable and energy efficient products. Ranges of values for γ and α, in Table 1.9, were estimated by observing the different environmental results obtained by the present base case and results obtained by previous analyses (Ardente and Mathieux, 2012)[18]. Variations of the results due to uncertainties on values of γ and α have been investigated in a sensitivity analysis (section 1.3.8.1).

Minor interventions, such as maintenance and repairs, during the useful service life of the device can be estimated as a percentage of mass of materials used to manufacture the washing machine (JRC, 2016b). This percentage is equal to 1 % (therefore ~696 g, see Table 1.2). The environmental burden of repair can be seen in Table 1.7, under the column 'Repair (R)'.

We assumed that the water consumption and the detergent consumption during the use phase can be considered constant for both A and B life cycles. Future work will explore the possibility of including variability for the two parameters.

In this section, the indexes for three environmental indicators are presented: GWP (as the climate change impact category is largely influenced by the use phase — 83.7 % overall); ADP elements (as the impact category is largely influenced by the production phase — 98 % overall); and freshwater eutrophication (potentially influenced by the impact of detergents). Charts are shown with the energy efficiency parameter (fraction between the energy consumption during the use phase of product (B) and the energy consumption during the use phase of product (A)) on the X-axis and the durability index calculated with equation (1) on the Y-axis. Initially (Figure 1.4, Figure 1.5 and Figure 1.6), the incremental environmental impact to make A more durable and the manufacturing impact variation between products B and A are assumed to be null ($\alpha = 0$; $\gamma = 100$ %).

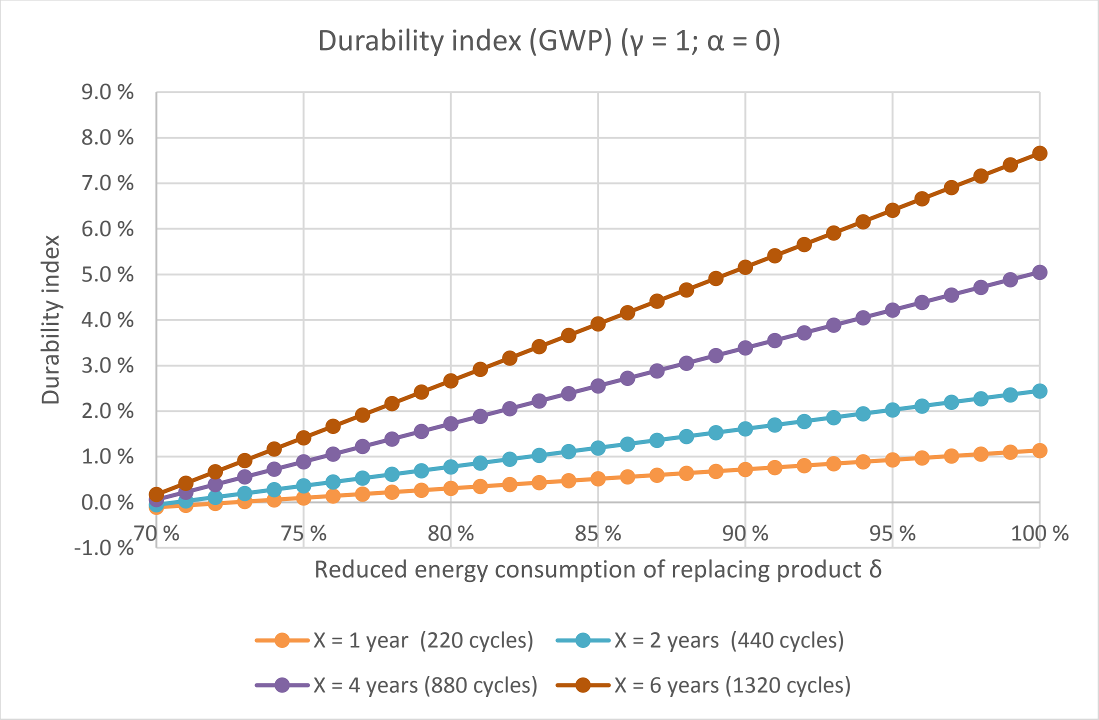

Figure 1.4. Analysis of durability index for GWP with γ = 100 % and α = 0 %

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[18] It is noticed that the impact assessment presented by Ardente and Mathieux (2012) did not consider same boundary conditions or inputs (including the impact of detergents), and therefore impact categories cannot be directly compared. However, these studies considering different machines of different market segments can be used to have an idea of the range of variation of impacts between older and newer products and impacts of more durable products.

In Figure 1.4, the durability index is always positive when δ is equal or higher than 72 %, considering the worst scenario of X = 1 year (or 220 additional washing cycles). When X is assumed to be 6 years (1 320 washing cycles) the durability index is positive in the considered range of δ and reaches about + 8 % if δ is 100 %, meaning product (B) has the same energy efficiency as product (A).

On the other hand, in Figure 1.5 the durability index trends are always positive and almost independent from the parameter δ. This occurs because the impact category is barely affected by the use phase, while the main contributor to results, as explained in Section 1.3.5, comes from the materials used for manufacturing. As a result, durability indexes range from 6.9 % to 46.4 % depending on the lifetime extension parameter X.

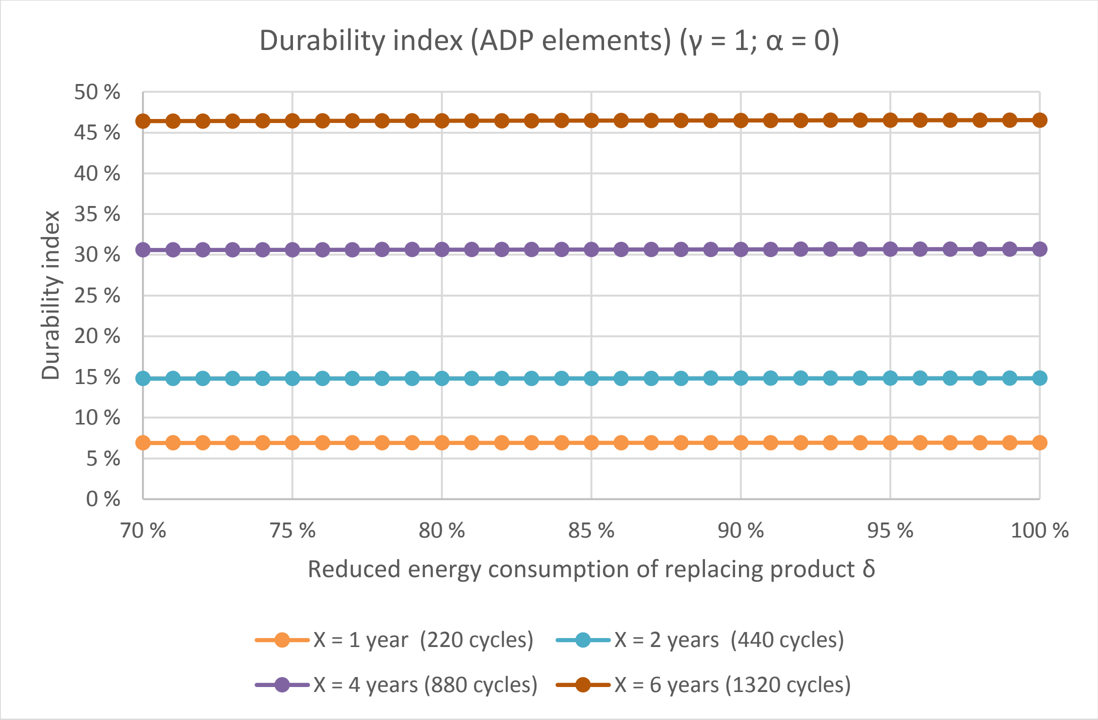

Figure 1.5. Analysis of durability index for ADP elements with γ = 100 % and α = 0 %

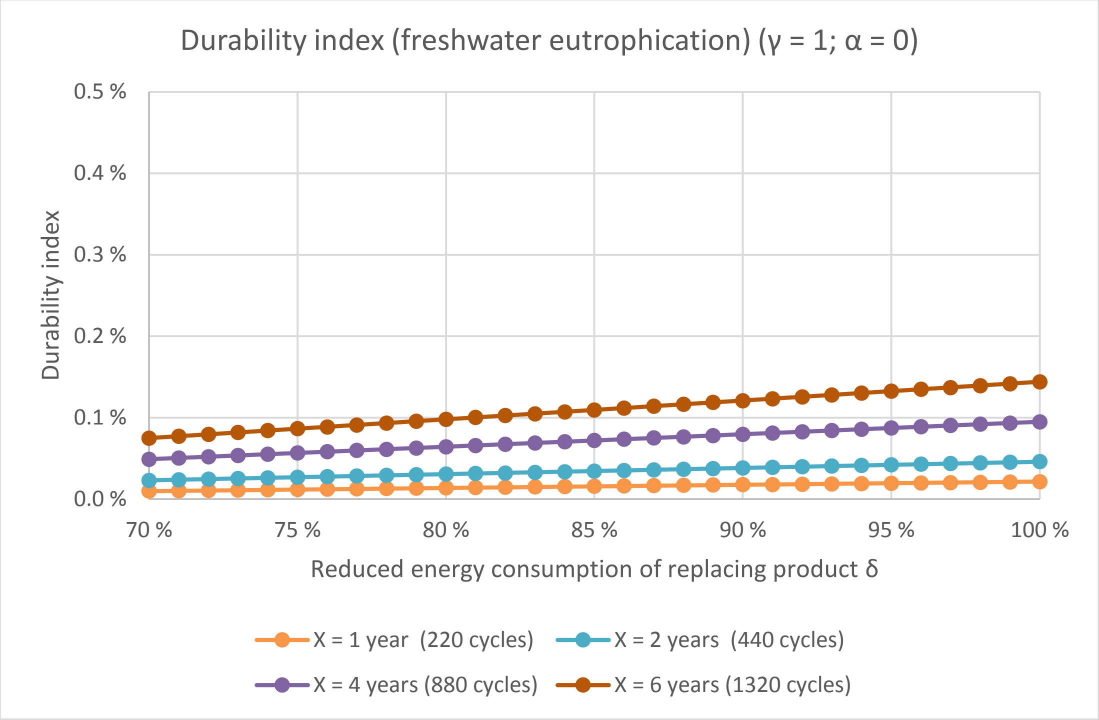

Figure 1.6. Analysis of durability index for freshwater eutrophication with γ = 100 % and α = 0 %

A different situation can be faced when freshwater eutrophication is analysed (Figure 1.6). For this impact category, durability index trends have a clear relationship with the parameter δ, even though this is not as evident as in the case of GWP. As in the previous case (ADP elements) durability indexes are always positive when δ is in the range 70-100 %, however values of the durability index are relatively small and in general are never higher than 0.2 %. This is mainly due to the fact that the impact category is most influenced by the use of detergents, a parameter that is considered constant for the durability analysis; thus, durability indexes that depend mainly on the energy consumption improvement provide less relevant variations.

1.3.8.1. Influence of parameters α and γ

Impacts of future generations of WM (i.e. product B) were estimated considering the existing variation in the BoM of the present WM base case, WM1 and WM2 (Table 1.2). Different scenarios were explored for the three impact categories GWP, ADP elements and Freshwater eutrophication. The following charts will show durability index trends in the following configurations.

1. γ min, α min.
2. γ min., α max.
3. γ max., α min.
4. γ max., α max.

- For GWP: γ min. = 75 %, γ max. = 125 %, α min. = 0 %, α max. = 30 %.
- For ADP elements: γ min. = 150 %, γ max. = 200 %, α min. = 0 %, α max. = 60 %.
- For freshwater eutrophication: γ min. = 75 %, γ max. = 125 %, α min. = 0 %, α max. = 30 %.

Durability analysis for GWP. Figure 1.7 provides an overview of the possible configurations of α and γ, and the following durability index trends. The greater environmental benefit can be gained when γ is 125 % and α is null; in this scenario durability indexes are always positive and, when δ = 100 %, they can be identified in the range 1.5-9.6 % (for X = 1-6 years). On the other hand, if γ is 75 % and α is 30 %, durability indexes are positive when $\delta \geq$ 87 % (X = 6 years) or ≥ 90 % (X = 1 year).

Durability analysis for ADP elements. As previously stated, the durability index for this impact category is almost independent from the parameter δ. This is confirmed in the four scenarios depicted in Figure 1.8. Values are always positive and nearly constant with a variable δ. The maximum environmental benefit can be gained when the lifetime extension is 6 years: from 41.7 % (when γ = 150 % and α = 60 %) to 94.1 % (when γ = 200 % and α = 0 %).

Durability analysis for freshwater eutrophication. The results of the analysis again show positive values for δ in the range 70-100 % (Figure 1.9) in the majority of configurations, however with values always smaller than 0.2 % in the best conditions. For this impact category it is possible to say that the effect of the δ, γ and α parameters does not influence the durability analysis, as freshwater eutrophication is mainly dependent on the use of detergents.

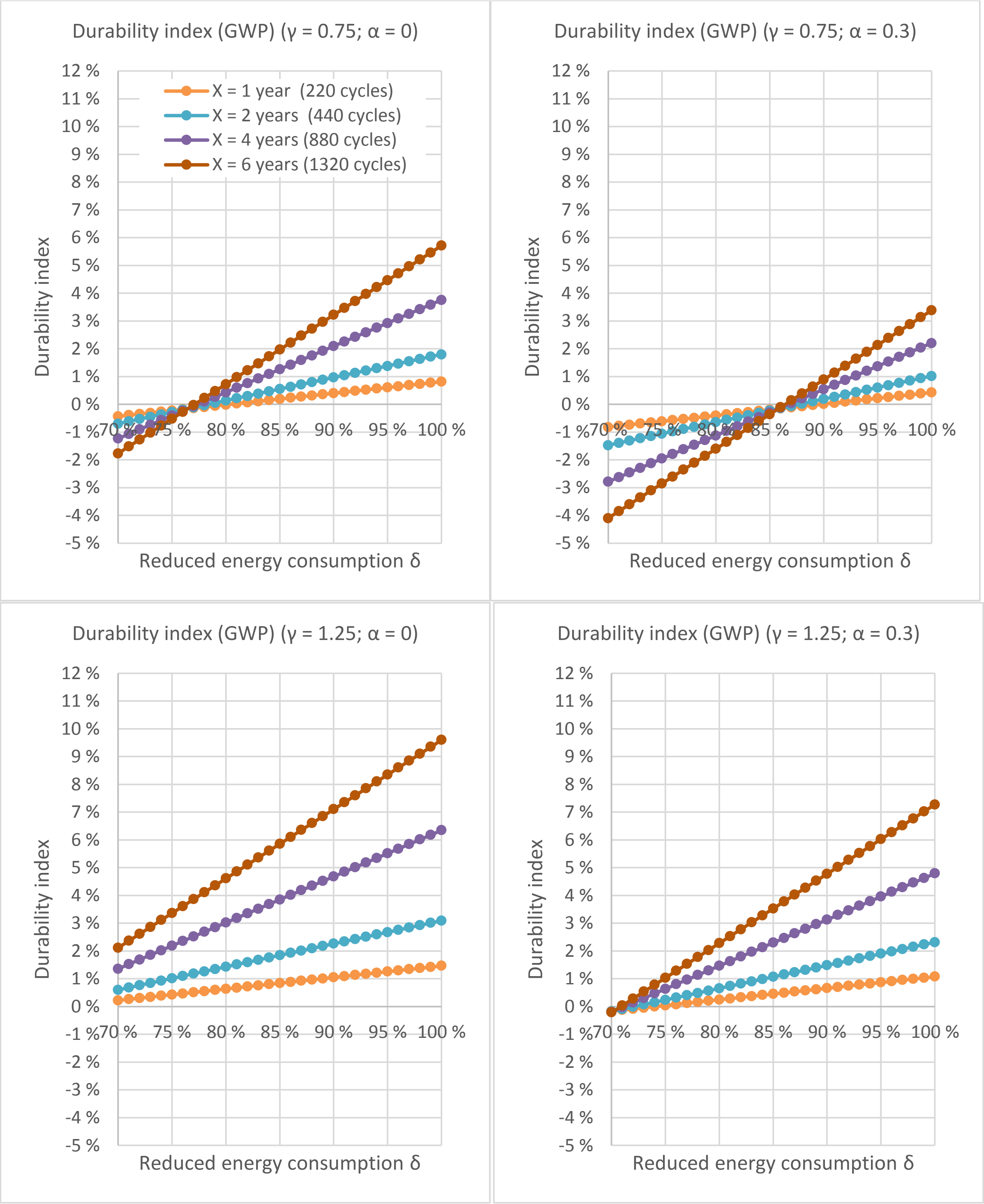

Figure 1.7. Analysis of durability index for GWP with γ and α variable

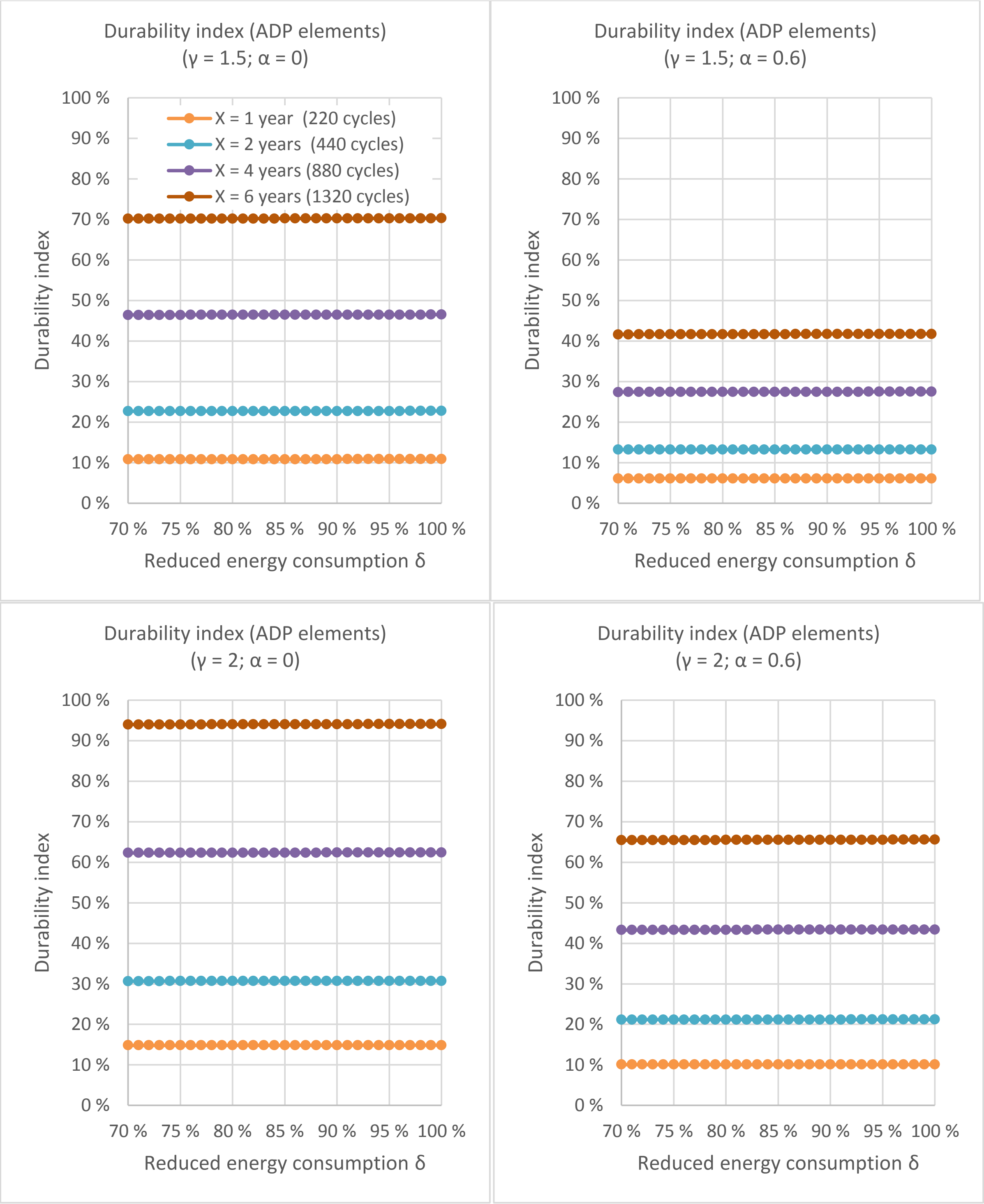

Figure 1.8. Analysis of durability index for ADP elements with γ and α variable

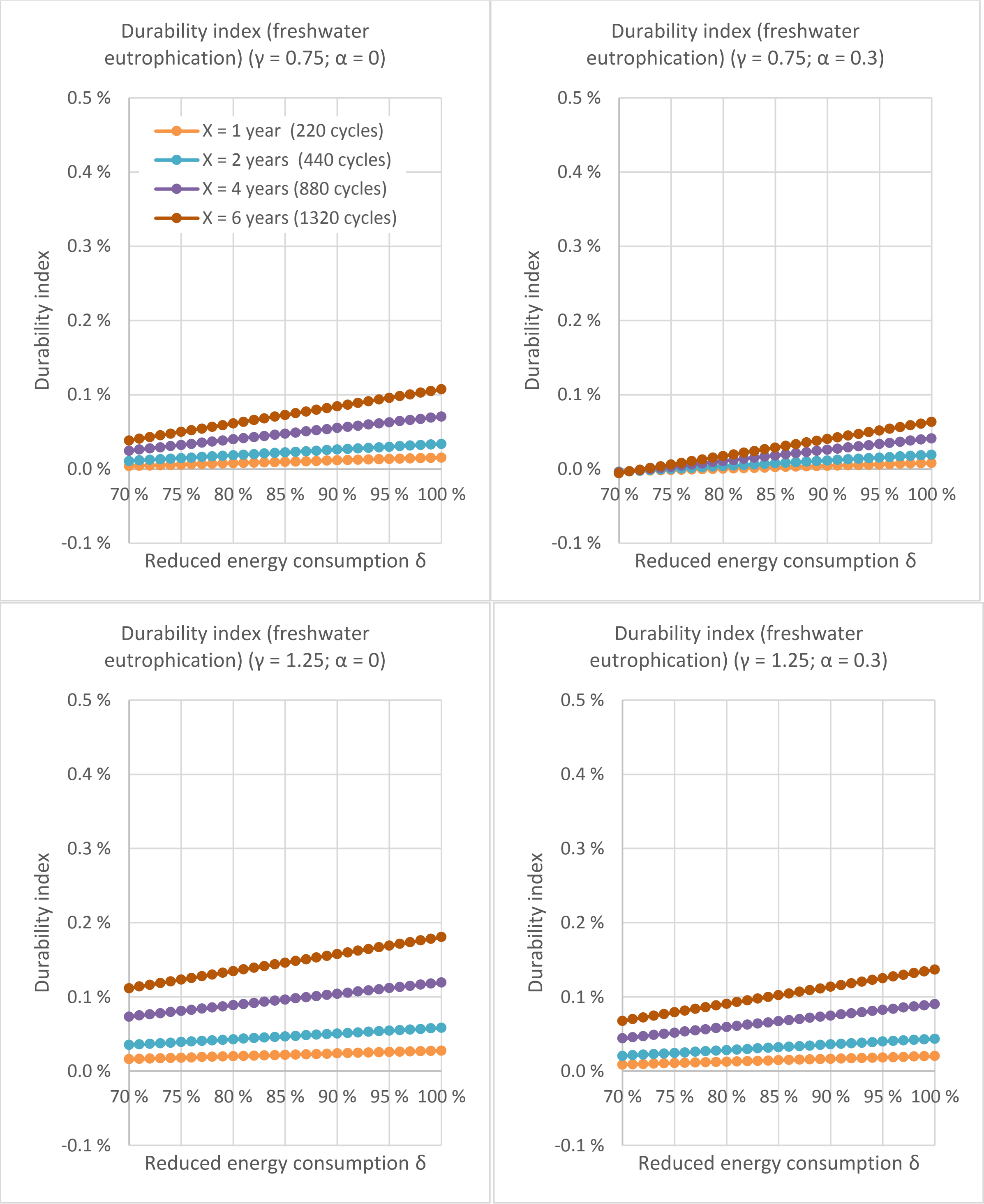

Figure 1.9. Analysis of durability index for freshwater eutrophication with γ and α variable

1.3.9. Comparison with previous durability analysis

In the hypothesis of considering γ = 100 % and α null (the incremental environmental impact to make the WM base case more durable), a comparison with the previous results on durability analysis (Ardente et al., 2012) is presented in this section. Ardente et al. used case studies WM1 and WM2 (2012) to conduct the environmental assessment, as reported in Table 1.8, considering 11.4 years as the operating time T during the durability analysis. It is important to underline that the comparison is for indicative purposes only, as two different systems were analysed and the two case studies WM1 and WM2 (2012) did not consider the use of detergents, nor the waste water treatment, in the LCA study. While Ardente et al. did not consider the variability of the α parameter, they made different assumptions for the parameter R, namely the additional treatments (e.g. maintenance, repair, use of spare parts) that were necessary during the operating time of the product:

- Present-study repair: 1 % of the materials used for the initial manufacturing;
- case studies WM1 and WM2 (2012): additional treatments accounted as incremental environmental impacts, + 10 % for Abiotic depletion potential and + 2.5 % for global warming (low repair scenario, LRS).

The comparison can be observed in the following charts, representing durability indexes for similar indicators: GWP and ADP elements. Figure 1.10 shows the comparison of durability indexes calculated by Ardente et al. (green and red lines) and the index calculated in this study for the GWP indicator (in blue). When the lifetime extension is equal to 1 year (upper part of the chart) it is possible to observe a slight improvement, of about 0.5 % on average (δ in the range 70-100 %), compared to WM1, while the trend of WM2 almost overlaps. On the other hand, when the lifetime extension is pushed to 4 years (lower part chart) it is possible to observe a different slope, resulting in a more relevant average improvement of about 1.2 %, compared to WM1, and a decrease of about 1.6 % with respect to WM2. It is important to remark that the different slope, however, allows a positive durability index for the present WM base case, with δ in the range 70-100 %.

The same comparison is presented in Figure 1.11 for ADP elements. In the first case the durability index has increased by about 8.1 % for both WM1 and WM2 when X = 1 year, while the increase is in the range of 6.0-6.6 % when X = 4 years.

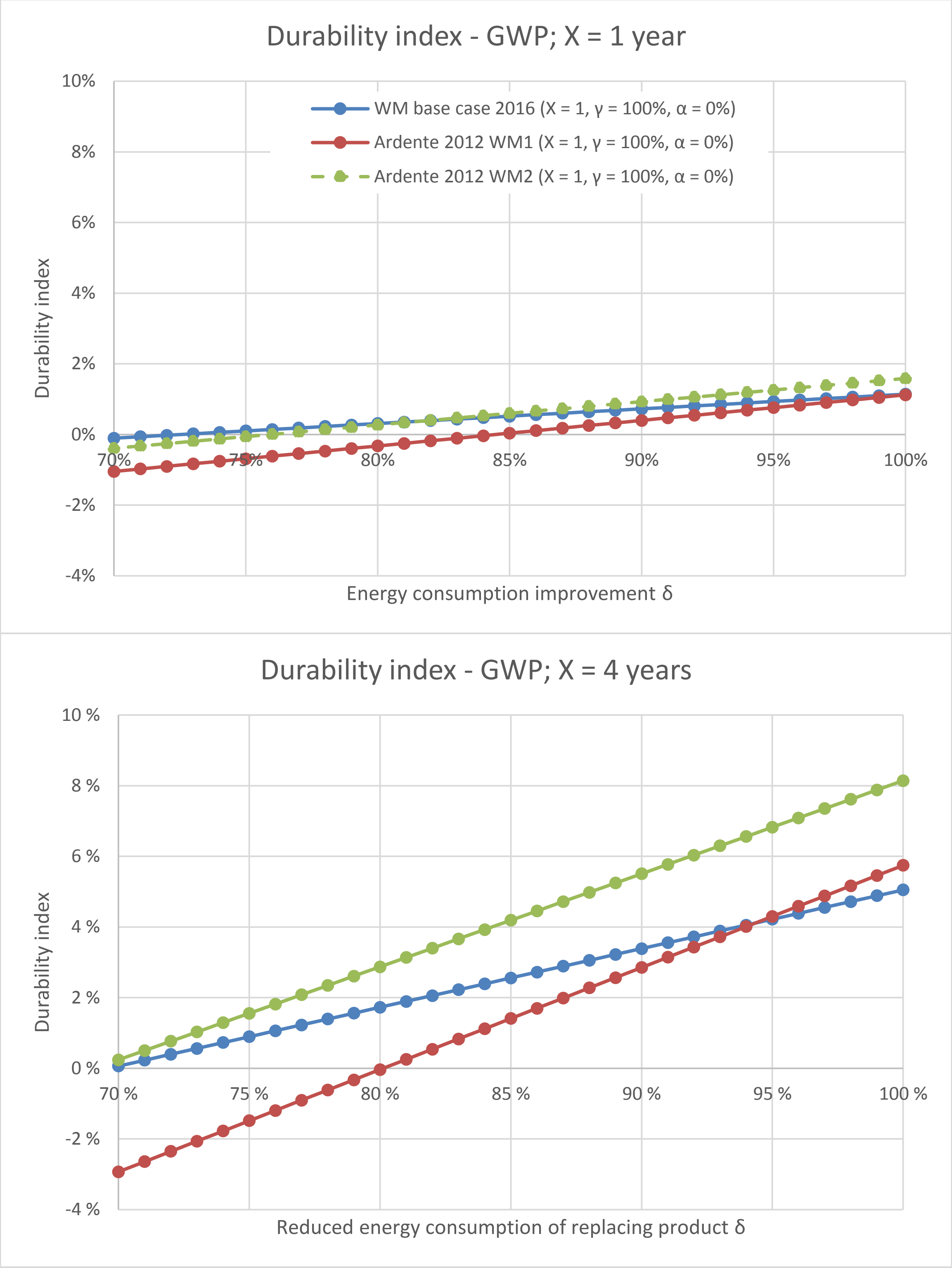

Figure 1.10. Durability index comparison for GWP — X = 1 in the upper graph, X = 4 in the lower graph

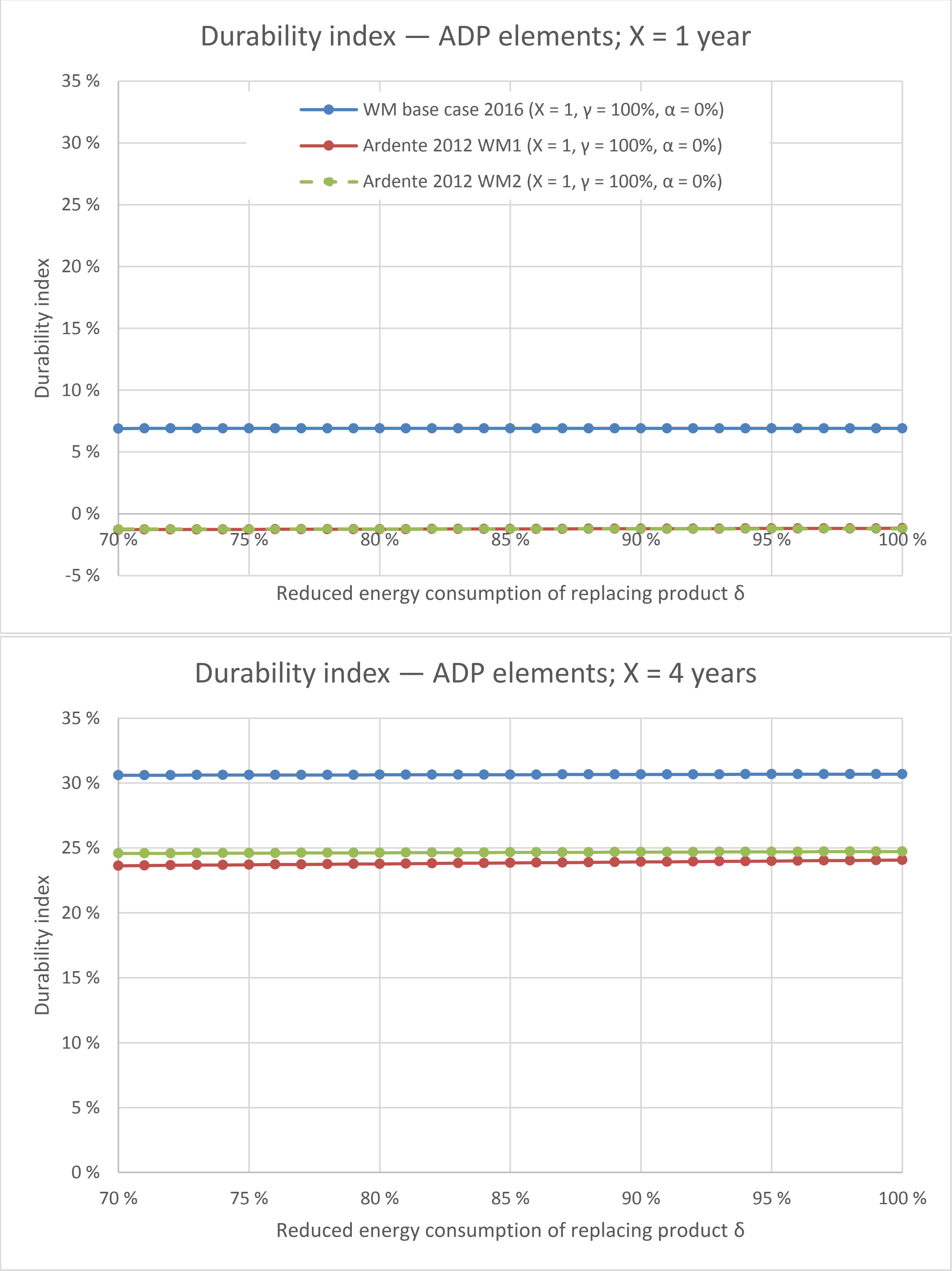

Figure 1.11. Durability index comparison for ADP elements — X = 1 in the upper graph, X = 4 in the lower graph

1.3.10. Conclusion of the WM case study

This section concludes the durability analysis of washing machines, an analysis conducted on a WM base case to understand what the environmental consequence (impact or benefit) could result from the extension of the lifetime of a device beyond the average lifetime expectancy. Several parameters have been included in this analysis: the technological progress and the possibility to have a newer product (B) with a higher energy efficiency (parameter δ) and different manufacturing impacts (parameter γ), but also the possibility to have incremental impacts to make the WM base case more durable (parameter α). The durability analysis is based on results obtained by the LCA study, therefore it is important to provide some final remarks before discussing durability indexes.

The LCA based on the present WM base case is not directly comparable to the LCAs of case studies WM1 and WM2 (2012), as the systems are characterised by different assumptions, different boundary conditions and different functional units (especially because of a different BoM and a different use-phase scenario). However, indicative conclusions could be drawn to delineate the variability of the parameters for the durability analysis. The various BoM of the present WM base case has a clear effect on the abiotic depletion of elements, especially due to the use of copper, stainless steel and electronic components. The use phases were modelled using different hypotheses, especially for the use rate and for the energy consumption per cycle. Another source of variability is represented by the specific impact per unit of kWh of electricity, which has recently changed at the inventory level. This change is characterised by an updated energy mix that resulted in a variation of specific impacts between the present and the previous analysis (e.g. the average GWP impact for the EU electricity mix is 0.473 kg CO_2 eq./kWh, whereas it used to be 0.590 kg CO_2 eq./kWh). The EoL phase of the LCA model does not take into account environmental credits from material recycling.

Concerning the durability analysis, final remarks depend on the selected impact category. Three impact categories were selected as representative of the overall set of environmental results: climate change (measured as GWP), abiotic depletion of elements and freshwater eutrophication.

Prolonging the WM base case lifetime produces limited environmental benefits for the freshwater eutrophication. However, freshwater eutrophication is mainly influenced by the impact of the detergent used during the use phase. Thus, durability indexes resulted not very relevant for the freshwater eutrophication (always below + 0.2 % of the life cycle impacts). This assessment was based on impacts of detergents assessed by (Golsteijn et al., 2015). The use of low-content phosphorous could result in the reduction of the freshwater eutrophication impact, up to 90% (JRC, 2016b). This would imply that, even if the same benefits are achieved in absolute terms, these would be more relevant in a life perspective (i.e. having higher values of the durability index for this impact category). Future analyses will explore the possibility of estimating the amount and the type of detergent used during washing cycles and of updating the durability index formula by introducing the variability of impacts for this parameter as well.

Considering the results showed in Section 1.3.8, prolonging the lifetime of the WM base case is environmentally beneficial for the climate change impact category (GWP indicator, mainly affected by the use phase) in the large majority of the considered scenarios. Excluding relevant variations of impacts in manufacturing new products or incremental impacts to make the WM base case more durable, prolonging the WM lifetime is environmentally convenient when δ (the energy consumption of the newer product (B) replacing the WM base case) is higher than 72 % of the consumption of the base case (Figure 1.4). Accounting for higher impact variations for manufacturing (Figure 1.7), the environmental benefit is ensured when the energy consumption of the newer product (B) is not greater than or equal to 90 % of the WM base case.

Finally, for the ADP elements indicator (mainly influenced by material use during the production phase), prolonging the WM base case lifetime was always beneficial. The environmental impact can be reduced by about 46 % when the operating life is extended by 6 years and about 7 % for an extension of 1 year (γ = 100 %, α null). When manufacturing impact variations for the newer product are included (γ = 150 %), and excluding incremental impacts to make the WM base case more durable (α null), the two percentages become 70 % and 11 %. These percentages reach respectively 65 % and 10 % if we consider γ = 200 % and α = 60 %.

Even though the different systems (present WM base case versus WM1 and WM2 2012 analyses) are not directly comparable, we attempted to build Figure 1.10 and Figure 1.11, aiming to show how these various systems behave. The GWP performance of the present WM base case, in terms of durability analysis, is in an intermediate position, compared to WM1 and WM2 (2012); the last two devices were chosen to represent a low/medium-level product and a medium/high-level product on the market. Moreover, regarding ADP elements, the durability index trends of the present WM base case are higher than the results obtained in the previous analysis. It is important to underline that extending the operational lifetime of the product generally results in an environmental benefit, which however varies depending on the selected impact category and other assumptions on the parameters.

1.4. Durability analysis of dishwashers

1.4.1. Presentation of the case study: DW base case

The case study in this section consists of an exemplar DW representing the average EU product, as several appliances of similar functionalities have been compiled to obtain a final base case, called the ‘DW base case’ hereinafter.

In particular, one of the products analysed in the revision of the preparatory study on DW (JRC, 2016a) was selected, and assessed by means of the MEErP methodology (EcoReport, 2014). The base case refers to a household dishwasher with a nominal rated capacity of 13 place settings (ps). The device is a full-size household dishwasher, which accounted for approximately 85 % of the market in Europe in 2014. The main features and key data are summarised in Table 1.10. Values of energy and water consumption have no direct correspondence with energy-label classes, as real-life conditions were considered to estimate the two figures.

Table 1.10. Main characteristics and key data for the DW base case (modified from (JRC, 2016a), based on private communications with the authors of the preparatory study)

Present DW base case features		
Nominal rated capacity	13	ps
Width	60	cm
Use rate	280	cycles/year
Annual energy consumption [19]	292	kWh/year
Annual water consumption [18]	3 057	l/year
Detergent consumption	20	g/cycle
Rinsing agent	3	g/cycle
Regeneration salt	19	g/cycle
Lifetime	12.5	years

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[19] Consumptions in real-life conditions estimated through a survey among users, conducted in March-April 2015 across Europe (JRC, 2016a)

1.4.2. Goal and definition of scope

The goal of the environmental analysis consists of updating the LCA study on a household dishwasher representative base case, and eventually updating the durability analysis conducted by Ardente and Talens Peiró (2015).

The functional unit used for this analysis consists of one dishwasher with a lifetime expectancy of 12.5 years, as presented in 1.4.1.

The scope of the analysis consists of the dishwasher life cycle, considering a cradle-to-grave system boundary. As defined in Section 1.2.1, production phase (P), use phase (U), repair (R) and end of life (E) are considered. The impacts of regeneration salt and detergents, including end-of-life treatment and depuration of waste water in a waste water treatment plant, are included in the system boundaries and allocated to the use phase.

As in the previous case study (Section 1.3), the end of life (E) includes the activities (manual and mechanical treatments) in a WEEE recycling plant. Further treatments (waste streams transport, incineration, landfilling, etc.) are considered out of scope. Environmental credits due to materials or energy recovery are not considered in the LCA model.

1.4.3. Life cycle inventory

1.4.3.1. Data collection

The data collection for the BoM is based on the revised preparatory study (JRC, 2016a), developed thanks to the input provided by manufacturers. A total of four BoMs of different full-size household DW models were considered to obtain the DW base case. The detailed BoM of the DW base case is specified in Table A.2 of Annex A. Table 1.11 illustrates an aggregated BoM, using five categories related to the materials used for the device (plastics, ferrous metals, non-ferrous metals, electronics, other materials) and an additional category for packaging. The BoM used in the previous analysis conducted by Ardente and Talens Peiró (2015) is also summarised in the same table; Ardente and Talens Peiró based their analysis on ISIS (2007) data, referring to a household DW with nominal rated capacity of 12 ps.

Table 1.11. Bill of materials of the DW base case (JRC, 2016a) and the DW case study, defined by the previous preparatory study (household dishwasher with nominal rated capacity of 12 ps) conducted by Ardente and Talens Peiró (2015)

Material categories	Present DW base case *(mass in g)*	DW case study (2015) *(mass in g)*
Plastics	10 873.3	8 338
Metals (ferrous)	21 553.6	27 266
Metals (non-ferrous)	5 831.2	1 374
Electronics	1 381.5	448
Other materials	8 140.2	10 732
Packaging	1 332.9	2 542
Total	**49 112.7**	**50 700**

The comparison of the two BoMs shows that the overall mass has changed slightly over years, with a decrease in the use of steel and ferrous metals. At the same time, a large increase is observed in the presence of plastic components (from 16 % to 22 %), non-ferrous metals (from 3 % to 12 %) and electronics (from 1 % to 3 %). However, it is important to recall that the nominal rated capacity of the DW case study (2015) was 12 ps, versus 13 ps for the present base case.

The data collection for the other phases of the DW life cycle was principally based on the ongoing preparatory study. Again, few deviations were adopted in order to have a comparable system boundary to Ardente and Talens Peiró (2015), needed for the durability analysis, and also to adapt input and output to data available in commercial software used for LCA. Table 1.12 summarises main hypothesis concerning the DW life cycle.

Table 1.12. Life cycle phases and relevant aspects concerning the DW life cycle

Life cycle relevant aspect	**Main assumptions**
Transport of materials to the manufacturing plant	For each material category, an average transport of 300 km by lorry was added, representing the shipping of the material to the point of processing
Plastics processing	An average injection moulding operation was used to represent the processing of plastic components
Ferrous metals processing	An average sheet stamping and bending operation was used to represent the processing of ferrous components
Non-ferrous metals processing	An average die-casting operation was used to represent the processing of non-ferrous components
Electronics	The 'electronics' group of components was detailed by means of own estimations based on the information provided by stakeholders. The assumed breakdown of electronics, in terms of percentages of the total mass, is the following: cables 38 %; printed circuit board (PCB) 37 %; switches 1 %; motor 8.6 %; display 2 %; other electronics 13.4 %
Assembly phase	Both power and thermal energy consumption were estimated for one device according to Ardente and Talens Peiró (2015): electricity consumption 17.31 kWh; thermal energy 9.2 kWh
Transport and distribution of the device to the final user	The transport and distribution of the product to the final consumer was modelled according to the MEErP

Life cycle relevant aspect	Main assumptions
	background data, therefore sea transport (12 000 km), rail transport (100 km) and transport by lorry (1 660 km) (Kemna, 2011)
Use phase — energy consumption	A lifetime of 12.5 years and an annual energy consumption in real-life conditions of 292 kWh/year were considered; the overall energy use was assumed to be equal to 3.65 MWh per life cycle and modelled using the low-voltage European electricity mix
Use phase — water consumption	A water consumption of 9.75 litres/cycle was considered, and the total water consumption was assumed equal to 34 m^3 per life cycle; the same amount of water is assumed to be drained as waste water
Use phase — detergents, rinsing agents, salt	A detergent consumption of 20 g/cycle and a regeneration salt consumption of 19 g/cycles were considered. The use of rinsing agents (about 0.8 kg/year) was not considered as no specific LCI datasets were available. Midpoint impacts from (Arendorf et al., 2014)
Repair	Repair was modelled with an amount of spare parts equal to 1 % of the DW base-case mass; spare parts are delivered to the final user with an average transport of 160 km by lorry; no additional energy is supposed to be used for maintenance
Transport of the device to the end-of-life facility	An average transport of 100 km by lorry was added, representing the delivery of the waste machine to the recycling plant
End of life	The DW base case and the spare parts are assumed to be treated by a WEEE recycling plant (Ardente and Mathieux, 2014b); waste packaging is assumed to be destined to a different stream and recycled
End of life processing	The DW base case and the spare parts are assumed to be processed by a

Life cycle relevant aspect	Main assumptions
	combination of manual and mechanical treatments (see Ardente and Talens 2015); the overall energy use was assumed to be equal to 0.066 kWh/kg of WEEE [20] and modelled using the medium-voltage European electricity mix

The mass composition of the 'Electronics' category (see Figure 1.12) was modelled as follows, based on private communications with stakeholders:

- Cables 38 %, associated with a 3-core cable dataset (100 g/m).
- Switches 1 %, associated with a tactile switch dataset.
- Other electronics 13.4 %, associated with a ring core coil (with housing) dataset, as the main components are inductors, chokes, valves or filaments.
- Specific components of the 'Electronics' category were modelled through GaBi datasets, using the BoM available in the ecoinvent database:
    - PCB 37 %, implemented as a Pb-free PCB dataset, available in the ecoinvent database[21] — a breakdown of the PCB components, available in the ecoinvent dataset, is reported in Table A.3 of Annex A;
    - display 2 %, implemented as an LCD glass dataset, available in the ecoinvent database[22];
    - motor 8.6 % wt, implemented as an electric motor dataset (material inputs for 1 kg of electric motor: low-alloyed steel sheet 0.75 kg, aluminium 0.165 kg and copper 0.09 kg), available in the ecoinvent database[23].

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[20] Treatment of waste electrical and electronic equipment, shredding, GLO, ecoinvent operation.

[21] Printed wiring board production, surface mounted, unspecified, Pb free.

[22] LCD glass, at plant, GLO.

[23] Electric motor, electric vehicle, at plant, RER.

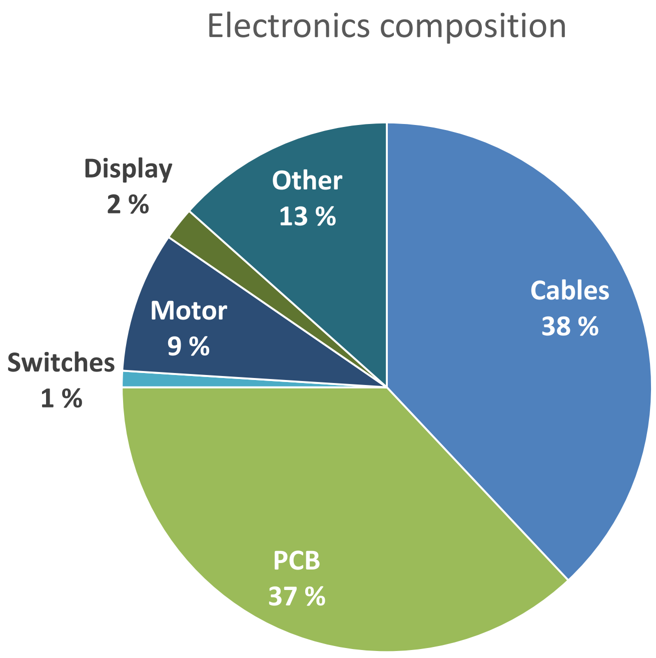

Figure 1.12. Electronic composition (total mass 1 381.5 g)

1.4.3.2. LCI background data

The commercial software (GaBi) was used to build the LCA model, including two databases for life cycle data (Professional Database and Extension Database XI: Electronics).

The LCA model was built considering:

- average road transport by lorry, 22 t;
- average rail transport by train, 726 t payload capacity;
- average sea transport by fuel-oil-driven cargo vessel, 27 500 t payload capacity;
- the European electricity mix, medium voltage, was used for manufacturing and EoL operations;
- the European electricity mix, low voltage, was adopted for the use-phase operation.

Regarding the assembly phase, the following assumptions were considered:

- electricity consumption modelled as European electricity mix, medium voltage;
- thermal energy modelled as energy from natural gas combustion.

Regarding the detergent, aggregate midpoint results for the life cycle of a dishwasher detergent were retrieved from Arendorf et al. (2014)[24]. Since a different assessment method was used to obtain the midpoint results presented by Arendorf et al., only environmental categories aligned with the ILCD assessment method, conversion factors and units of measurement were considered. This has reduced the set of indicators to the following.

- Climate change, measured by the GWP as kg of CO_2 equivalent.
- Ozone depletion, measured in kg CFC-11 equivalent.
- Eutrophication freshwater, measured in kg P equivalent.

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[24] The life cycle includes the impacts of ingredients, formulation, packaging, transport and end of life.

- Eutrophication marine, measured in kg N equivalent.
- Photochemical ozone formation, measured in kg NMVOC equivalent.
- Resource depletion water, measured in m^3 equivalent.
- Abiotic depletion (fossil), measured in MJ.

The complete set of environmental results of detergents is provided in Table A.5 of Annex A. Regarding the packaging, its waste flow is considered to occur during the DW use phase.

1.4.4. Life cycle impact assessment results

The results of the LCIA phase are summarised in Table 1.13. Figures are referred to the functional unit and totals are subdivided into: production, use phase and repair, and end of life. As in the previous analysis for WM, environmental credits from recycling or other recovery techniques were out of scope.

Table 1.13. Life cycle impact assessment. Results referred to the functional unit of one DW base case. P = production, assembly, distribution; U+R = use phase and repair; E = end of life

Impact category	**Totals**	**P**	**U+R**	**E**
Acidification (mole of H+ eq.)	**7.87E+00**	2.45E+00	5.42E+00	6.09E-03
Climate change (GWP) (kg CO_2 equiv.)	**2.33E+03**	3.08E+02	2.02E+03	1.33E+00
Ecotoxicity freshwater (CTUe)	**5.89E+02**	5.31E+02	5.80E+01	2.08E-01
Eutrophication freshwater (kg P eq.)	**1.55E-01**	1.47E-03	1.53E-01	2.46E-06
Eutrophication marine (kg N equiv.)	**3.62E-01**	2.11E-02	3.41E-01	5.95E-05
Eutrophication terrestrial (mole of N eq.)	**1.47E+01**	3.77E+00	1.09E+01	1.75E-02
Human toxicity, cancer effects (CTUh)	**7.21E-06**	5.59E-06	1.61E-06	1.84E-08
Human toxicity, non-cancer effects (CTUh)	**1.22E-04**	8.06E-05	4.13E-05	2.72E-08
Ionising radiation, human health (kBq U235 eq.)	**7.36E+02**	1.80E+01	7.18E+02	3.77E-01
Ozone depletion (kg CFC-11 eq.)	**3.38E-05**	2.70E-06	3.11E-05	1.33E-09
Particulate matter (kg PM2.5 equiv.)	**5.02E-01**	2.06E-01	2.95E-01	2.68E-04
Photochemical ozone formation(kg NMVOC)	**4.92E+00**	1.10E+00	3.81E+00	4.57E-03
Resource depletion water (m^3 eq.)	**3.19E+01**	1.40E+00	3.05E+01	2.18E-02
Abiotic depletion (ADP fossil) (MJ)	**2.71E+04**	4.52E+03	2.26E+04	1.59E+01
Abiotic depletion (ADP elements) (kg Sb equiv.)	**4.97E-02**	4.76E-02	2.13E-03	4.10E-07

Table 1.14. Life cycle impact assessment — contributors to results. Percentages referred to the functional unit of one DW base case. P = production, assembly, distribution; U+R = use phase and repair; E = end of life

Impact category	**Totals**	**P**	**U+R**	**E**
Acidification (mole of H+ eq.)	100.0 %	31.1 %	68.8 %	0.1 %
Climate change (GWP) (kg CO_2 equiv.)	100.0 %	13.2 %	86.7 %	0.1 %
Ecotoxicity freshwater (CTUe)	100.0 %	90.1 %	9.8 %	0.0 %
Eutrophication freshwater (kg P eq.)	100.0 %	1.0 %	99.0 %	0.0 %
Eutrophication marine (kg N equiv.)	100.0 %	5.8 %	94.1 %	0.0 %
Eutrophication terrestrial (mole of N eq.)	100.0 %	25.6 %	74.3 %	0.1 %
Human toxicity, cancer effects (CTUh)	100.0 %	77.4 %	22.3 %	0.3 %
Human toxicity, non-cancer effects (CTUh)	100.0 %	66.1 %	33.9 %	0.0 %
Ionising radiation, human health (kBq U235 eq.)	100.0 %	2.4 %	97.5 %	0.1 %
Ozone depletion (kg CFC-11 eq.)	100.0 %	8.0 %	92.0 %	0.0 %
Particulate matter (kg PM2.5 equiv.)	100.0 %	41.1 %	58.8 %	0.1 %
Photochemical ozone formation (kg NMVOC)	100.0 %	22.4 %	77.5 %	0.1 %
Resource depletion water (m^3 eq.)	100.0 %	4.4 %	95.5 %	0.1 %
Abiotic depletion (ADP fossil) (MJ)	100.0 %	16.7 %	83.3 %	0.1 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	100.0 %	95.7 %	4.3 %	0.0 %

1.4.5. Life cycle interpretation

Use and repair (U+R) and production (P) are the most relevant phases of the DW base-case analysis. While the use phase is dominated by the consumption of electricity, which is responsible of the majority of the impacts for several impact categories, the production phase contributes to more than 50 % for freshwater ecotoxicity, human toxicity (with both cancer and non-cancer effects), ozone depletion and abiotic depletion of elements.

A breakdown of the main contributors to the production and use and repair phases is provided in this section, in Table 1.15 and Table 1.16.

Table 1.15. Life cycle impact assessment — contributors to results. Percentages referred to the P column, representing the impacts of the P phase (production, assembly, distribution) for the functional unit of one DW base case

Impact category	**P**	Plastics	Metals [25]	Electronic comp.	Other[26]
Acidification (mole of H+ eq.)	**2.45E+00**	3.9 %	31.3 %	48.2 %	16.6 %
Climate change (GWP) (kg CO_2 equiv.)	**3.08E+02**	10.7 %	28.9 %	51.2 %	9.2 %
Ecotoxicity freshwater (CTUe)	**5.31E+02**	1.2 %	87.3 %	10.6 %	1.0 %
Eutrophication freshwater (kg P eq.)	**1.47E-03**	25.3 %	27.6 %	43.2 %	3.9 %
Eutrophication marine (kg N equiv.)	**2.11E-02**	31.0 %	15.2 %	46.6 %	7.3 %
Eutrophication terrestrial (mole of N eq.)	**3.77E+00**	5.1 %	22.1 %	41.8 %	31.0 %
Human toxicity, cancer effects (CTUh)	**5.59E-06**	11.3 %	31.3 %	51.8 %	5.6 %
Human toxicity, non-cancer effects (CTUh)	**8.06E-05**	5.9 %	68.1 %	24.9 %	1.2 %
Ionising radiation, human health (kBq U235 eq.)	**1.80E+01**	21.0 %	22.4 %	43.9 %	12.8 %
Ozone depletion (kg CFC-11 eq.)	**2.70E-06**	2.6 %	93.9 %	1.6 %	1.8 %
Particulate matter (kg PM2.5 equiv.)	**2.06E-01**	2.4 %	17.7 %	72.0 %	7.9 %
Photochemical ozone formation (kg NMVOC)	**1.10E+00**	6.0 %	23.7 %	40.8 %	29.5 %
Resource depletion water (m^3 eq.)	**1.40E+00**	16.7 %	14.5 %	59.3 %	9.5 %
Abiotic depletion (ADP fossil) (MJ)	**4.52E+03**	19.1 %	21.7 %	45.4 %	13.7 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	**4.76E-02**	0.1 %	54.0 %	45.9 %	0.0 %

Regarding the DW base-case production phase, the main impacts are due to the production of materials. Most of the environmental impacts are dominated by the contribution of electronic components (acidification; climate change; freshwater, marine and terrestrial eutrophication; human toxicity — cancer effects; ionising radiation; particulate matter, photochemical ozone formation, resource depletion — water; abiotic depletion — fossil). The PCB is playing a crucial role in the group of electronic components, as it is responsible for the most of the impacts. Concerning plastic components, the highest contributions to impacts are from eutrophication (freshwater and marine, with 25.3 % and 31 % of the overall production phase respectively); an important share is due to the use of polyurethane, for these categories. Metals play a relevant role for impact categories such as freshwater ecotoxicity (hotspot represented by the use of copper), ozone depletion (mainly due to the use of stainless steel) and abiotic depletion of elements (for which the impact of zinc is the main contributor).

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[25] Includes ferrous and non-ferrous components.

[26] Includes other materials, packaging, assembly and distribution.

Table 1.16. Life cycle impact assessment — contributors to results. Percentages referred to the U+R column, representing the impacts of the use phase and repair for the functional unit of one DW base case

	U+R	Electricity	Detergent and salt*	Water	Repair (R)
Acidification (mole of H+ eq.)	**5.42E+00**	97.7 %	1.1 %	0.7 %	0.5 %
Climate change (GWP) (kg CO_2 equiv.)	**2.02E+03**	84.0 %	15.2 %	0.7 %	0.2 %
Ecotoxicity freshwater (CTUe)	**5.80E+01**	82.0 %	2.7 %	6.1 %	9.2 %
Eutrophication freshwater (kg P eq.)	**1.53E-01**	2.3 %	97.0 %	0.7 %	0.0 %
Eutrophication marine (kg N equiv.)	**3.41E-01**	31.4 %	67.1 %	1.5 %	0.1 %
Eutrophication terrestrial (mole of N eq.)	**1.09E+01**	95.6 %	3.1 %	1.0 %	0.3 %
Human toxicity, cancer effects (CTUh)	**1.61E-06**	86.9 %	2.2 %	7.4 %	3.5 %
Human toxicity, non-cancer effects (CTUh)	**4.13E-05**	89.9 %	4.5 %	3.6 %	2.0 %
Ionising radiation, h. health (kBq U235 eq.)	**7.18E+02**	99.9 %	0.0 %	0.1 %	0.0 %
Ozone depletion (kg CFC-11 eq.)	**3.11E-05**	3.9 %	96.0 %	0.0 %	0.1 %
Particulate matter (kg PM2.5 equiv.)	**2.95E-01**	96.6 %	1.8 %	0.9 %	0.7 %
Photochemical ozone formation (kg NMVOC)	**3.81E+00**	72.8 %	26.1 %	0.8 %	0.3 %
Resource depletion water (m^3 eq.)	**3.05E+01**	61.0 %	18.1 %	20.9 %	0.0 %
Abiotic depletion (ADP fossil) (MJ)	**2.26E+04**	81.3 %	17.6 %	0.9 %	0.2 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	**2.13E-03**	25.9 %	51.1 %	0.4 %	22.5 %

* Contribution to results of detergent was not included for the impact categories not listed in section 1.4.3.2.

As previously stated, the use phase is dominated by the electricity consumption during the service life. The use of detergent and regeneration salt, however, affects the majority of freshwater eutrophication (97 %) and ozone depletion (96 %), while marine eutrophication (67.1 %) and abiotic depletion of elements (51.1 %) are influenced as well, but to a smaller extent. The use of low-content phosphorous could result in reduction of the freshwater eutrophication impact, up to 90% (JRC, 2016a). The contribution of repair to the abiotic depletion of elements is remarkable, with 22.5 % of the total U+R.

1.4.6. Analysis of the result of different case-studies

The main features and key data of the present DW base case and the DW case study used by Ardente and Talens Peiró (2015) are summarised in Table 1.17. Besides the different nominal rated capacity (13 ps versus 12 ps) and lifetime expectancy (12.5 years versus 12 years), it should be noted that different assumptions were used to calculate the average water and energy consumptions during the use phase.

Table 1.17. Main characteristics and key data for the present DW base case and the DW case study used by Ardente and Talens Peiró (2015)

Dishwasher features		**Present DW base case**	**DW case study (2015)**
Nominal rated capacity	ps	13	12
Use rate	cycles/year	280	280
Annual energy consumption	kWh/year	292	233
Annual water consumption	l/year	3 057	3 780
Lifetime	years	12.5	12

Due to the differences between the two systems, a direct comparison of these systems is not considered relevant, as in the previous case study focused on WM. Furthermore, Ardente and Talens Peiró (2015) used a different impact assessment method, and only a subset of environmental indicators could be considered for a comparison of the two sets of midpoint results.

It is again important to recall that different versions of LCA databases can influence LCIA results of systems; for instance, previous studies considered an average GWP impact for the EU Electricity mix of 0.590 kg CO_2 eq./kWh, whereas now the impact factor is 0.473 kg CO_2 eq./kWh.

A comparison, however, was made between the results of the current study and the results presented in the DW preparatory study (JRC, 2016a). In Figure 1.13 it is possible to observe the GWP for the functional unit of one DW with a lifetime of 12.5 years, evaluated with two different tools and databases. The total GWP for the present DW base case was shown to be 15 % higher than the result obtained with MEErP, which is mainly due to the use of a different database for LCI datasets and processes. Other indicators were not compared as the impact assessment method of the two tools (GaBi and MEErP) is different.

The total result obtained for present DW base case is 10 % higher than the result obtained with MEErP, which is mainly due to the use of different LCI datasets for energy and materials. Other indicators were not compared as the impact assessment methods of the two tools (GaBi and MEErP) are largely different.

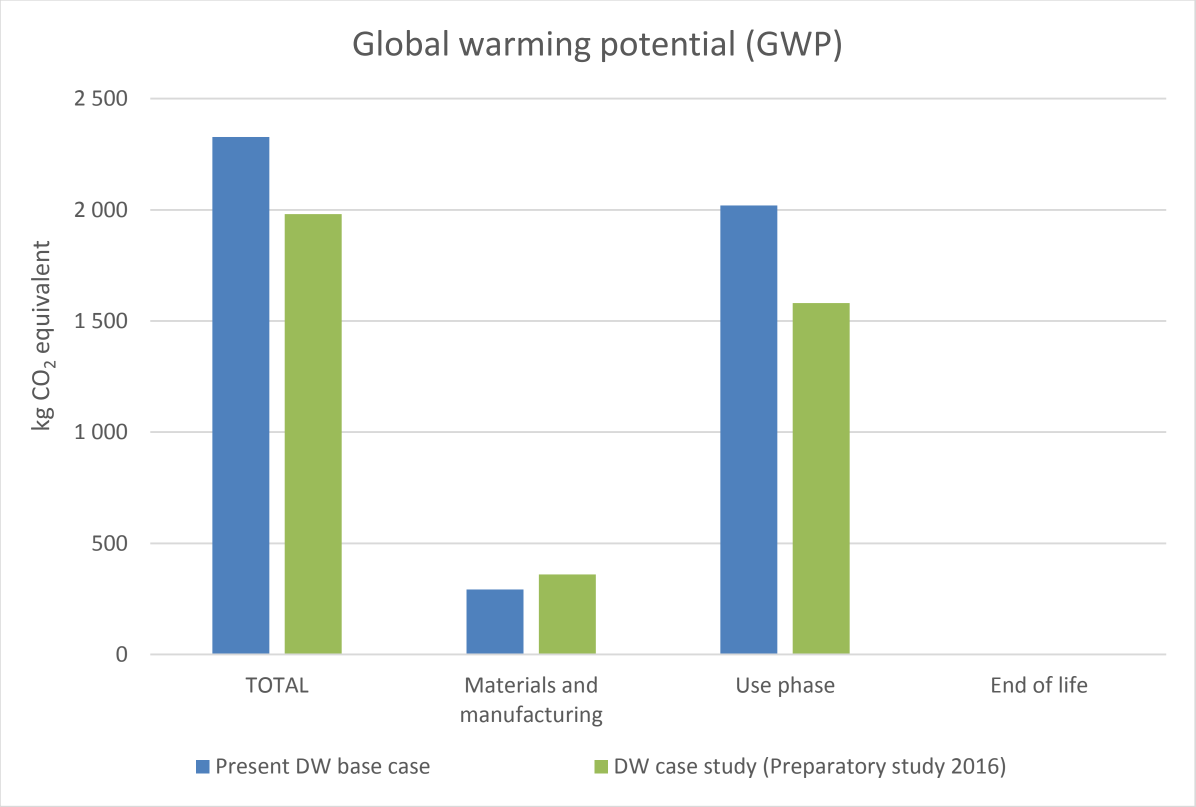

Figure 1.13. GWP comparison between two studies referred to dishwashers — the functional unit consists of one 'DW base-case' dishwasher with a lifetime of 12.5 years

1.4.7. Final remarks

The environmental analysis conducted on the present DW base case was developed to update the former analysis conducted by Ardente and Talens Peiró (2015), as this relatively recent work was however based on data from ISIS (2007). As stated also for the WM case study, we can confirm that use and production phases are the main contributors to environmental impacts of the DW base case. The use-phase impacts are mainly influenced by the energy consumption (especially acidification, GWP, ADP fossil and terrestrial eutrophication), detergents (marine and freshwater eutrophication, ozone depletion potential), and spare parts used during the repair (ADP elements). On the other hand, the production phase is mainly affected by the use of electronic components and metals (especially for ADP elements, GWP, ecotoxicity and human toxicity); the main contributors to these impacts originates from the impact of the printed circuit board and from the use of zinc, stainless steel and copper. Compared to the inventory data used by Ardente and Talens Peiró (2015) for their DW case study, the main differences were represented by the assumptions made to calculate the energy and water consumptions during the operational-use phase, whereas the expected lifetime has changed slightly (12.5 years instead of 12) and the frequency of use was the same (280 cycles/year).

Considering the total GWP results showed in Figure 1.13, the result for the present DW base case is about 15 % higher than the result obtained with MEErP, mainly due to the use of a different database for LCI datasets and processes.

1.4.8. Durability indexes for dishwashers

Several references for DWs' lifetimes are available in the literature. According to the preparatory study (JRC, 2016a) the useful operating life of a domestic dishwasher varies from 10 to 17 years; Van Holsteijn en Kemna BV (2005) provides the range 12-15 years, similarly to Johansson and Luttropp (2009), who reported 10-15 years, and to Zhifeng et al. (2012), with an average of 12 years. As in the previous case study, devoted to washing machines, in this case the considered lifetime is equal to 12.5 years.

Key data for the durability analysis are summarised in Table 1.18.

Values of γ and α (section 1.3.8) are generally affected by uncertainty, since these refer to potential newer replacing products compared to the product under analysis. The durability assessment method therefore adopts a wide range of variation of these parameters to explore different scenarios. In particular, the analysis of different LCA studies in different years can help to derive information about the evolution of the impacts for the considered product group, including impacts of more durable and energy efficient products. Ranges of values for the parameter γ were estimated by observing the different environmental results obtained by the present DW base-case analysis, which is based on the ongoing preparatory study, and results obtained by Ardente and Talens Peiró (2015), based on the 2007 preparatory study. Variations of the results due to uncertainties on values of γ and α have been investigated in a sensitivity analysis (section 1.4.8.1).

Table 1.18. Main characteristics and key data for the durability analysis

Characteristics	**Value**	**Unit**
Use rate	280	cycles/year
Annual energy consumption (in real-life conditions)	292	kWh/year
Lifetime (operating time **T**)	12.5	years
Operating time extension **X** (variable)	1-6	years
Energy consumption improvement $\boldsymbol{\delta}$ (product (B) compared to (A))	70-100 %	
Manufacturing impact variation $\boldsymbol{\gamma}$ (product (B) compared to (A))	variable	
$\boldsymbol{\gamma}$ for GWP	75-125 %	
$\boldsymbol{\gamma}$ for ADP elements	150-200 %	
$\boldsymbol{\gamma}$ for freshwater eutrophication	75-125 %	
Incremental environmental impact to make A more durable (A') $\boldsymbol{\alpha}$	variable	
$\boldsymbol{\alpha}$ for GWP	0-30 %	
$\boldsymbol{\alpha}$ for ADP elements	0-60 %	
$\boldsymbol{\alpha}$ for freshwater eutrophication	0-30 %	

Minor repairs during the useful service life of the device can be estimated as a percentage of initial mass of materials used to manufacture the dishwasher (JRC, 2016a). This percentage is again equal to 1 % (therefore ~491 g, see Table 1.11). The environmental impact of repair can be seen in Table 1.16, under the column 'Repair (R)'. It is assumed here that water, detergent, rinsing agent and regeneration salt consumption during the use phase can be considered constant for both A and B life cycles. Future work will explore the possibility of including the variability of these parameters, especially for water and detergent consumptions.

In this section, the indexes for three environmental indicators are presented: GWP (as the climate change impact category is largely influenced by the use phase — 86.7 % overall), ADP elements (as the impact category is largely influenced by the production phase — 95.7 % overall) and freshwater eutrophication (potentially influenced by the impact of detergents). Charts are built with the energy efficiency parameter (fraction between the energy consumption during the use phase of product (B) and the energy consumption during the use phase of product (A)) on the X-axis and the durability index calculated with equation (1) on the Y-axis. Initially (Figure 1.14, Figure 1.15 and Figure 1.16), the incremental environmental impact to make A more durable and the manufacturing impact variation between product (B) and (A) are assumed to be null ($\alpha = 0$; $\gamma = 100$ %).

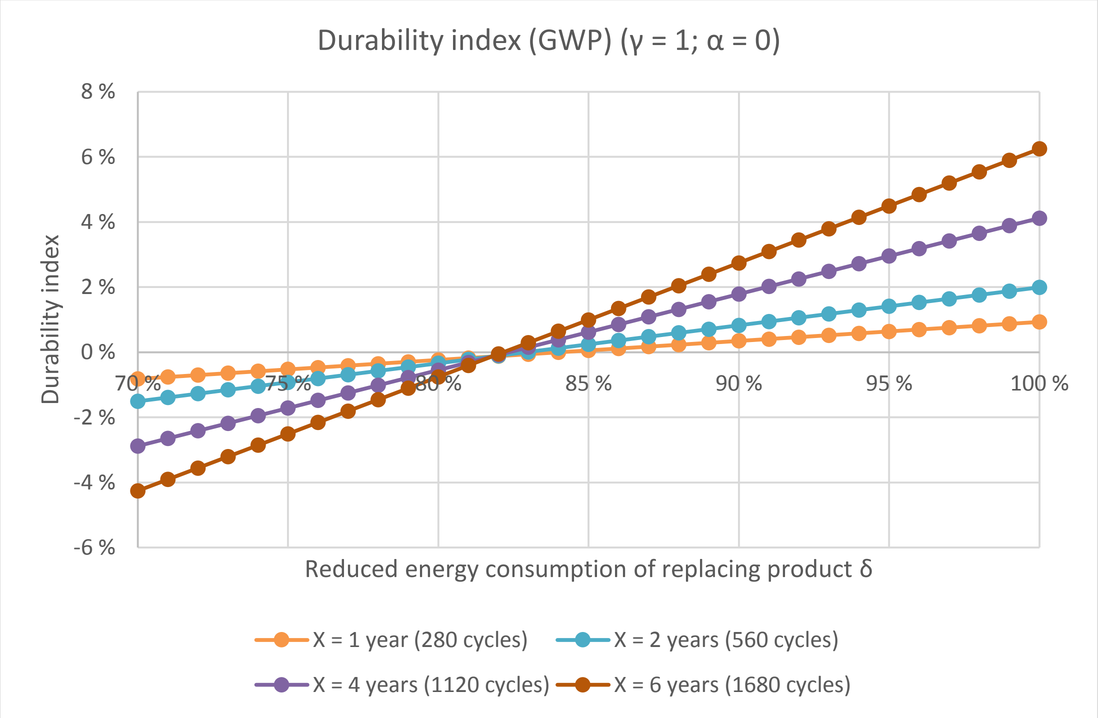

Figure 1.14. Analysis of durability index for GWP with $\gamma = 100$ % and $\alpha = 0$ %

In Figure 1.14, the durability index was calculated for the GWP indicator, according to equation (1), with X variable from 1 to 6 years (it was 1-4 years in Ardente and Talens Peiró (2015)). The durability index is positive for δ equal or to higher than 85 % for X = 1 year, or for δ equal or higher than 83 % for X = 6 years. Considering this last case, it results that prolonging the lifetime of the DW base case by 6 years (1 680 washing cycles) would produce a decrease in the GWP by about 2.7 % compared to replacement with a new machine that is 10 % more energy efficient. When $\delta = 100$ %, the index exceeds 6 %.

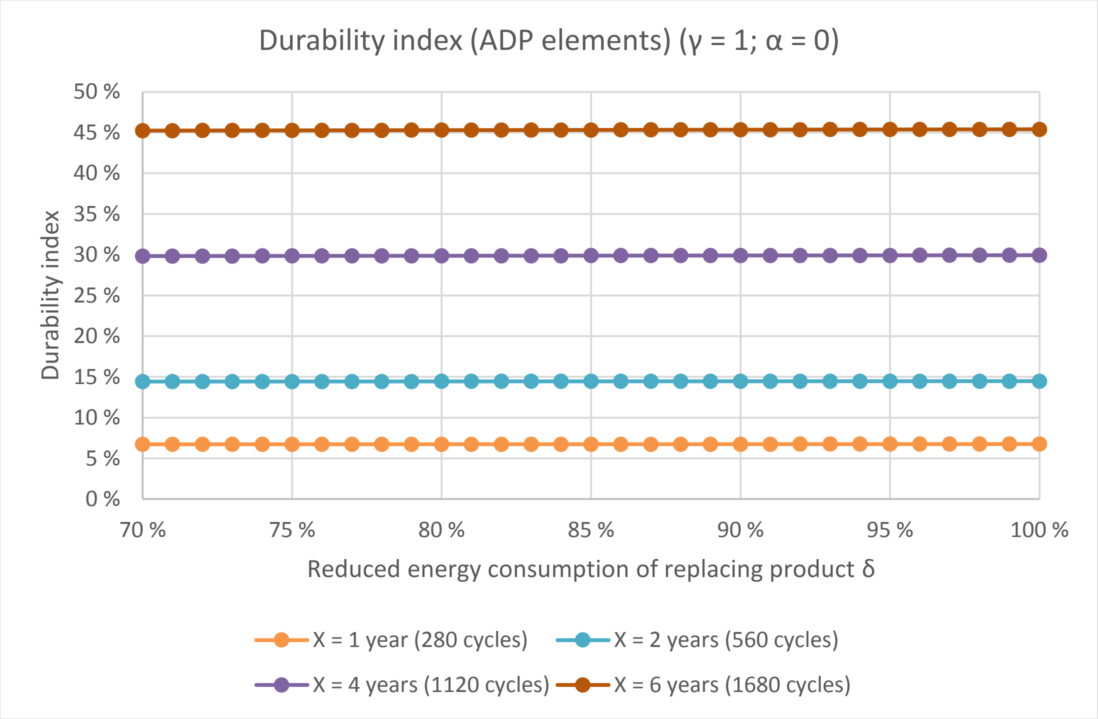

Figure 1.15. Analysis of durability index for ADP elements with γ = 100 % and α = 0 %

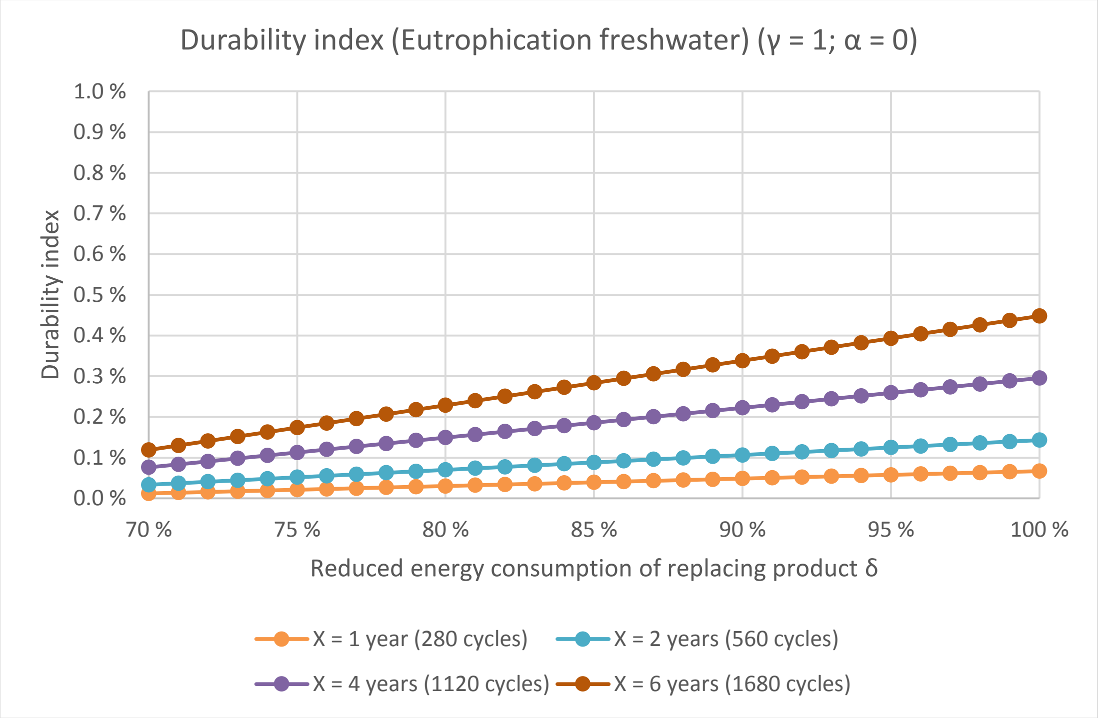

Figure 1.16. Analysis of durability index for freshwater eutrophication with γ = 100 % and α = 0 %

What is described for ADP elements in the washing machine chapter is confirmed for this case study, as shown in Figure 1.15. Durability index trends are always positive and almost independent from the parameter δ. Also in this case the impact category is barely affected by the use phase, while the main contributor to results comes from the materials used for manufacturing (see Section 1.4.5). As a result, durability indexes range from 6.7 % to 45.2 % depending on the lifetime extension parameter X.

When the durability analysis concerns the freshwater eutrophication impact category (Figure 1.16), it is possible to observe durability indexes that are always positive and directly proportional to δ when this parameter is in the range 70-100 %. However, durability index values are in general always lower than 0.5 %, meaning that the impact category is barely influenced by variations in the energy consumption, while the main contributors to results come from the use of detergents (Table 1.13 and Table 1.16), which is considered constant for the durability analysis.

1.4.8.1. Influence of parameters α and γ

Under the same considerations as Section 1.3.8.1, ranges of values for γ and α were estimated by observing the different environmental results obtained by the present base cases (both WM and DW) and the results obtained by previous analyses (Ardente and Mathieux, 2012; Ardente and Talens Peiró, 2015)[27]. Thus, different scenarios were explored for the three impact categories: GWP, ADP elements and freshwater eutrophication. Impacts due to the production phase of future generations of washing machines (namely product (B) in the durability analysis) were estimated for the impact categories involved, considering the existing variation in the BoM of the present DW base case and the DW detailed by ISIS (2007), as summarised in Table 1.11. The configurations are summarised below.

1. γ min., α min.
2. γ min., α max.
3. γ max., α min.
4. γ max., α max.

- For GWP: γ min. = 75 %, γ max. = 125 %, α min. = 0 %, α max. = 30 %.
- For ADP elements: γ min. = 150 %, γ max. = 200 %, α min. = 0 %, α max. = 60 %.
- For freshwater eutrophication: γ min. = 75 %, γ max. = 125 %, α min. = 0 %, α max. = 30 %.

From the following charts it is possible to observe that:

- Figure 1.17 (durability analysis for GWP) shows how the durability analysis for this impact category is strictly connected to parameters γ and α, other than δ. The charts provide an overview of the possible configurations, and it can be seen how the greater environmental benefit can be gained when γ is 125 % and α is null. In this scenario, the durability indexes are positive when δ is higher than 80 % (for X = 1 year) and 78 % (for X = 6 years). When δ = 100 %, the durability index ranges from 1.2 % to 7.8 %. On the other hand, if γ is 75 % and α is 30 % the durability indexes are positive just when δ ≥ 93 % (X = 6 years) or ≥ 95 % (X = 1 year).
- Figure 1.18 (durability analysis for ADP elements) shows trends similar to the ones seen with the WM case study (Figure 1.8). The durability index for abiotic depletion (elements) is almost independent from the parameter δ. Indexes are always positive and nearly constant with a variable δ. The maximum environmental benefit can be gained when the lifetime extension is 6 years: from 40.8 % (when γ is 150 % and α is 60 %) to 91.8 % (when γ is 200 % and α is 0 %).

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[27] Ardente and Mathieux (2012) and Ardente and Talens Peiró (2015) did not consider detergents in their analyses.

- Figure 1.19 (durability analysis for freshwater eutrophication) presents the results of the analysis for freshwater eutrophication, showing trends barely influenced by main parameters of the analysis. The values are always positive when γ = 125 %, reaching almost 0.6 % when α is null and X = 6 years. On the other hand, negative values can be observed when γ = 75 %, with a minimum of – 0.1 % when α = 30 % and X = 6 years.

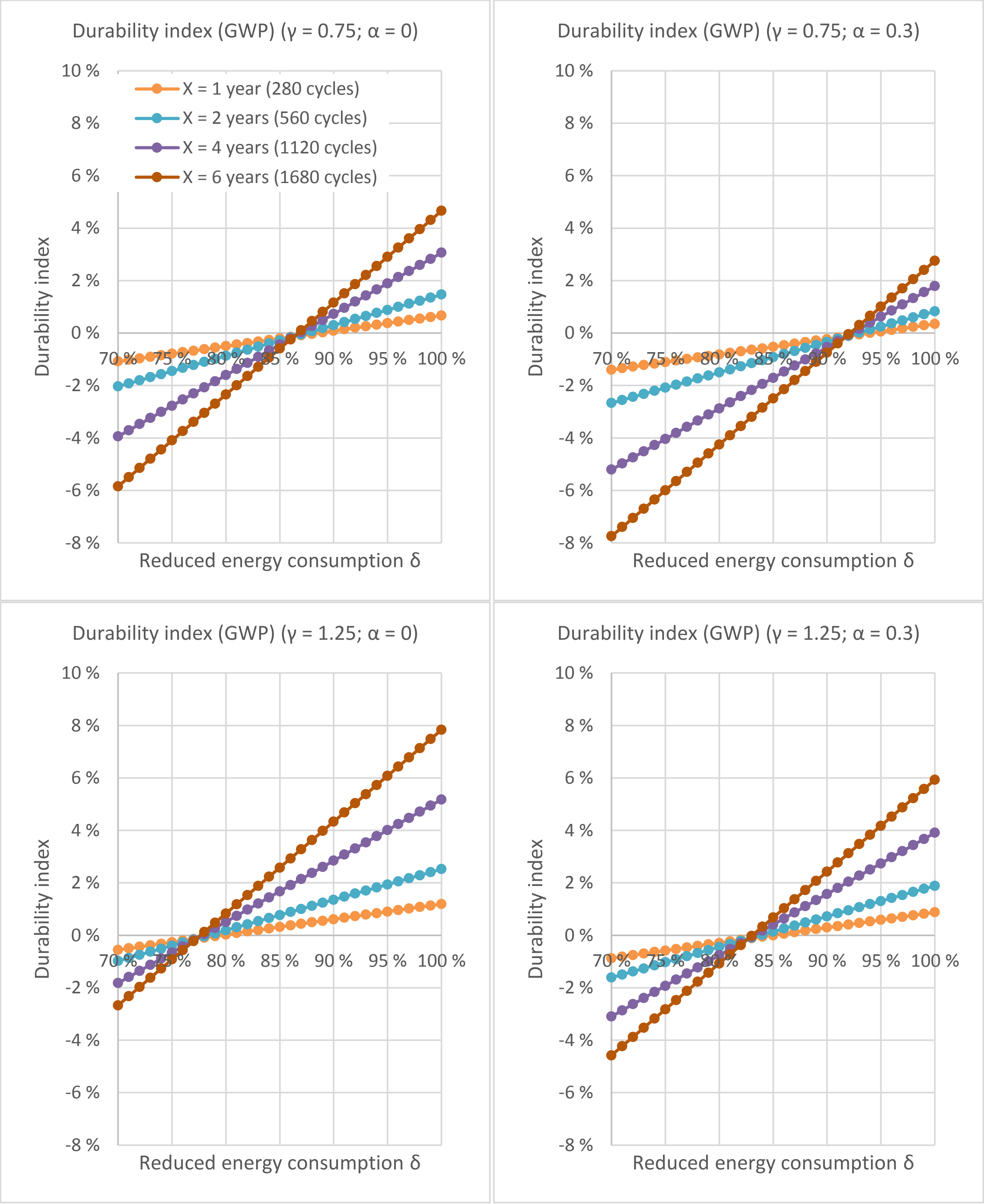

Figure 1.17. Analysis of durability index for GWP with γ and α variable

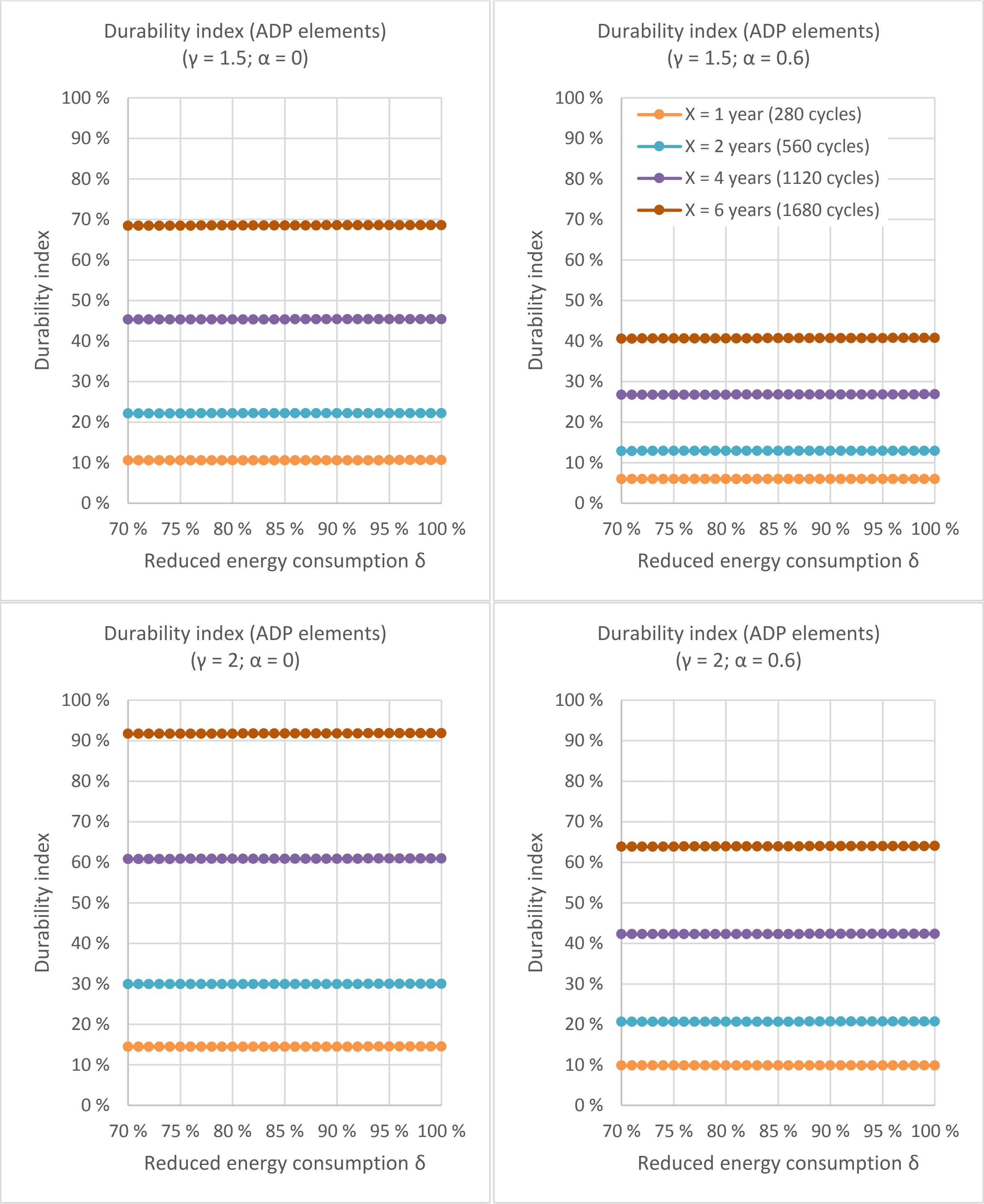

Figure 1.18. Analysis of durability index for ADP elements with γ and α variable

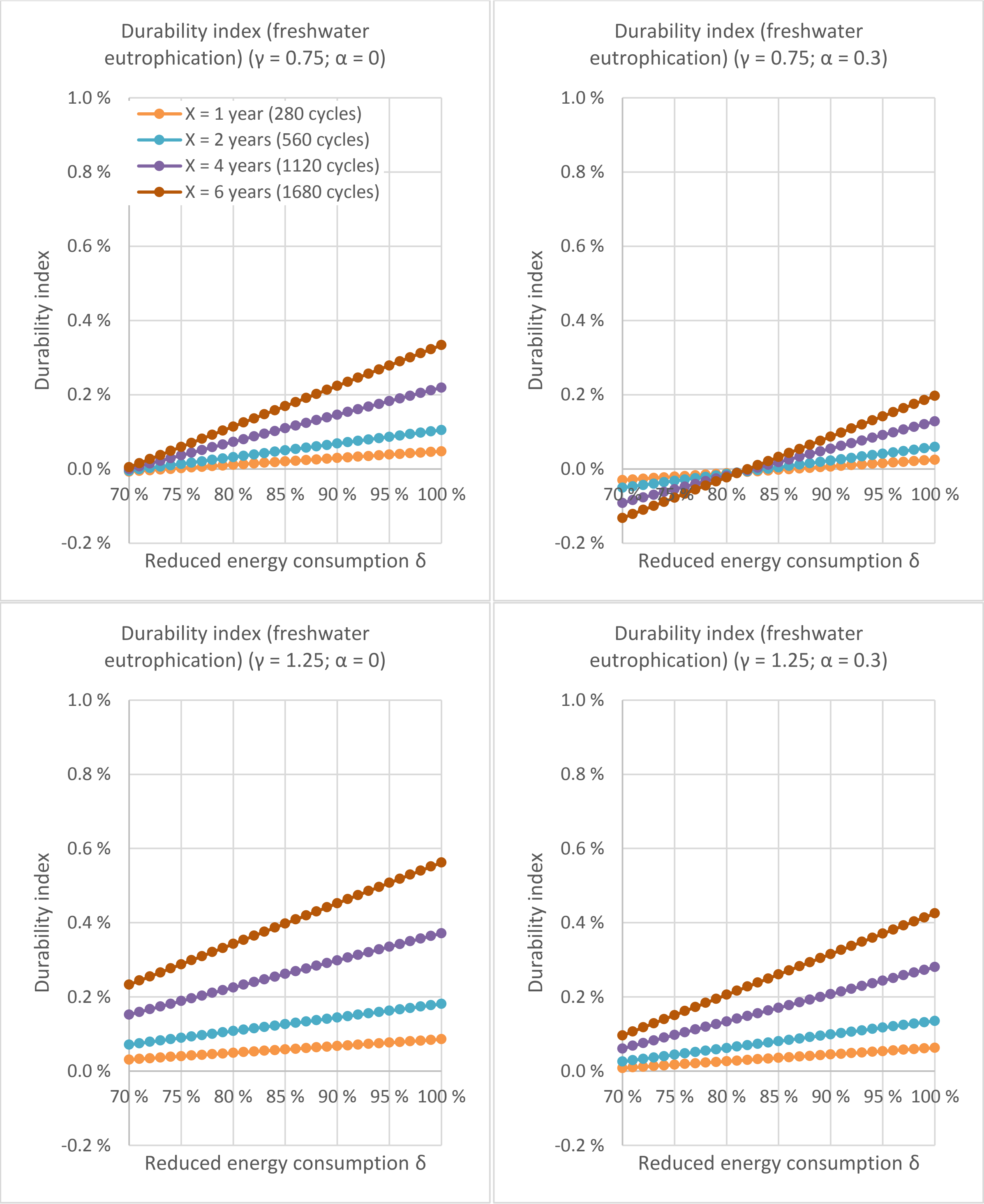

Figure 1.19. Analysis of durability index for freshwater eutrophication with γ and α variable

1.4.9. Comparison with the previous durability analysis

Assuming γ = 100 % and α = 0 %, a comparison with the previous results on durability analysis conducted by Ardente and Talens Peiró (2015) is presented in this section. Ardente and Talens Peiró (2015) considered 12 years as the operating time expectation (T) for the durability analysis and did not consider the variability of the α parameter. On the other hand, Ardente and Talens Peiró (2015) formulated different assumptions concerning the impacts of the parameter R, the additional treatments (e.g. maintenance, repair, use of spare parts) necessary during the operating time of the product:

- Present-study repair: 1 % of the materials used for the initial manufacturing;
- DW case study (Ardente and Talens Peiró, 2015): additional impacts accounted as a percentage of the considered impact categories, such as + 5 % for abiotic depletion potential, ecotoxicity, freshwater eutrophication and + 0.5 % for the other indicators (LRS[28]).

The comparison can be observed in the following charts, representing durability indexes for similar indicators: GWP, ADP elements and freshwater eutrophication.

Figure 1.20 shows the comparison of the durability indexes calculated by Ardente and Talens Peiró (2015) (red line) and the indexes calculated in this study for GWP (in blue). When the lifetime extension is equal to 1 year (upper chart) it is possible to observe a slight improvement, of about + 0.4 % on average (δ in the range 70-100 %), compared to DW (2015). When the lifetime extension is pushed to 4 years (lower chart) it is possible to observe a more relevant improvement of about + 2 % in average.

The same type of comparison is presented in Figure 1.21 for ADP elements. For an X equal to either 1 or 4 years, the durability index of the DW base case has increased by about 3.56 % and 2.85 %, respectively.

The last impact category, freshwater eutrophication, has been analysed. In this case, the durability indexes of the present DW case study are positive (i.e. environmental benefits) but tending to zero, mainly because the two analyses were conducted with different system boundaries (i.e. detergents excluded in the study of 2015). For this reason a direct comparison with the study 2015 for the freshwater eutrophication impact is considered unrepresentative.

It is important to underline that the comparison is for indicative purposes only, as two different systems were analysed and the case study analysed by Ardente and Talens Peiró (2015) did not consider the use of detergents, nor waste water treatment, in the LCA study.

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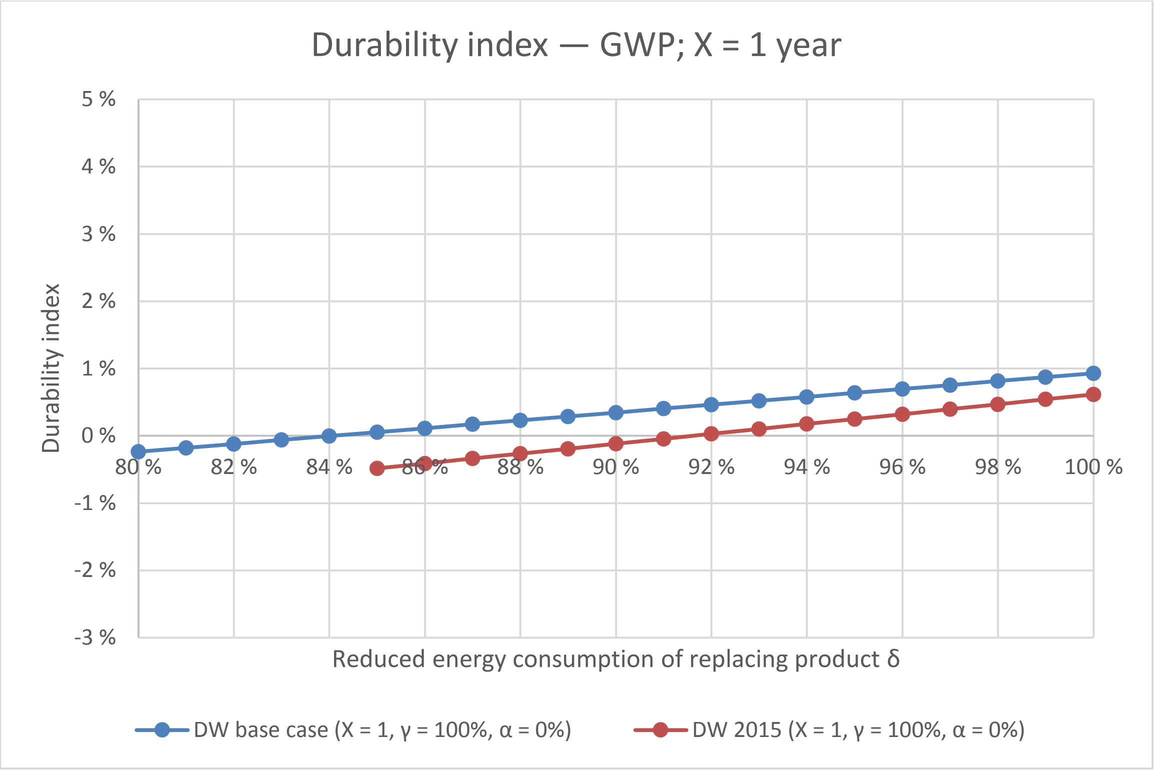
[28] The study by Ardente and Talens Peiró (2015) also considered a high repairing scenario (HRS) in which higher impacts for repair were assumed. This scenario will be not considered for the current analysis.



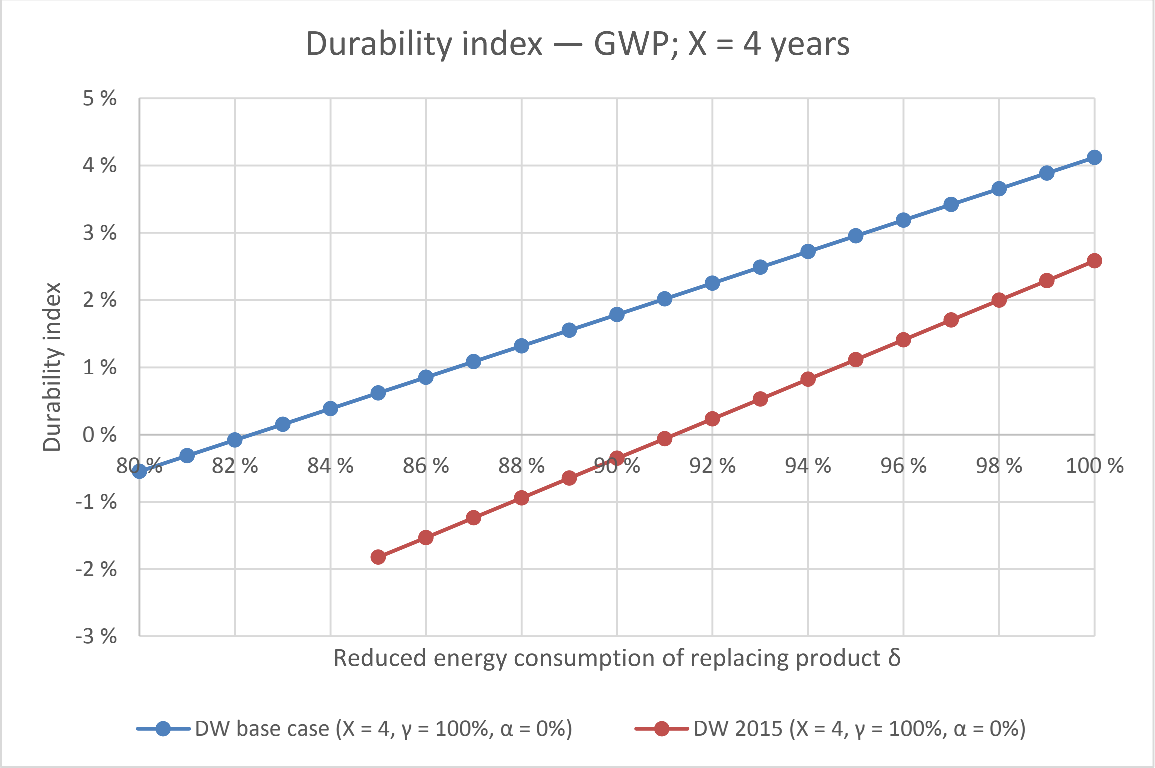
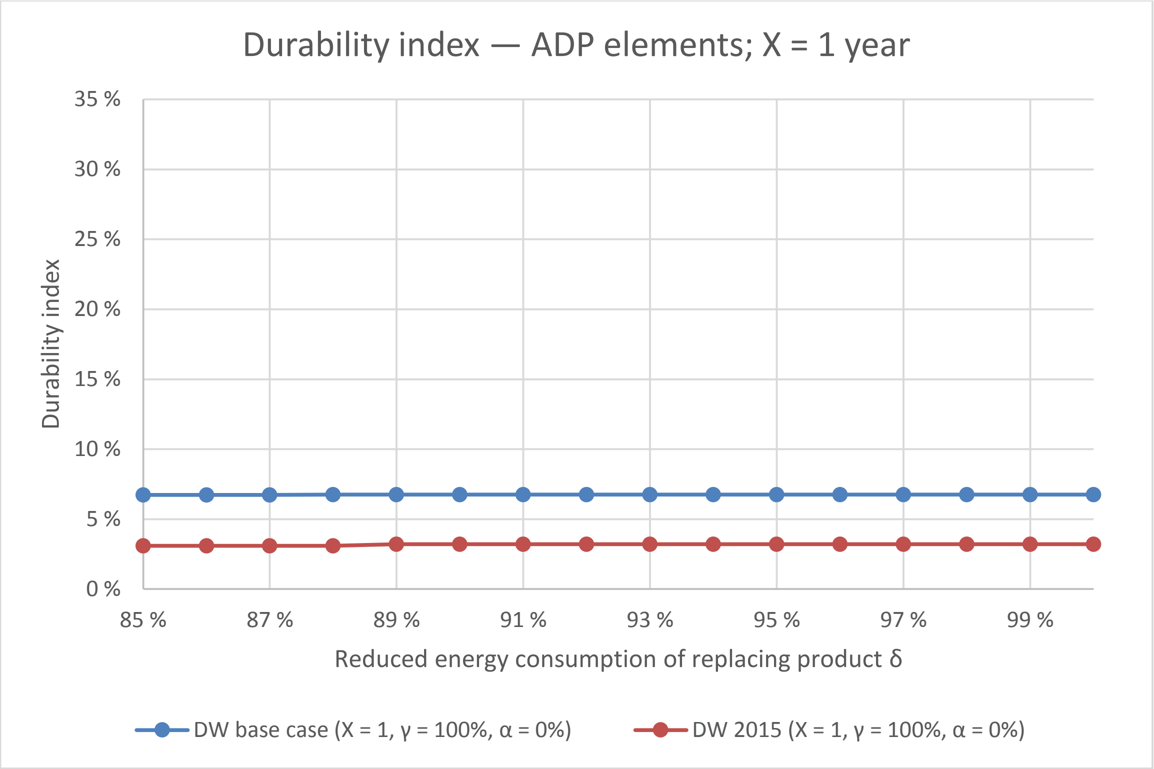


Figure 1.20. Durability index comparison for GWP. X = 1 in the upper graph, X = 4 in the lower graph



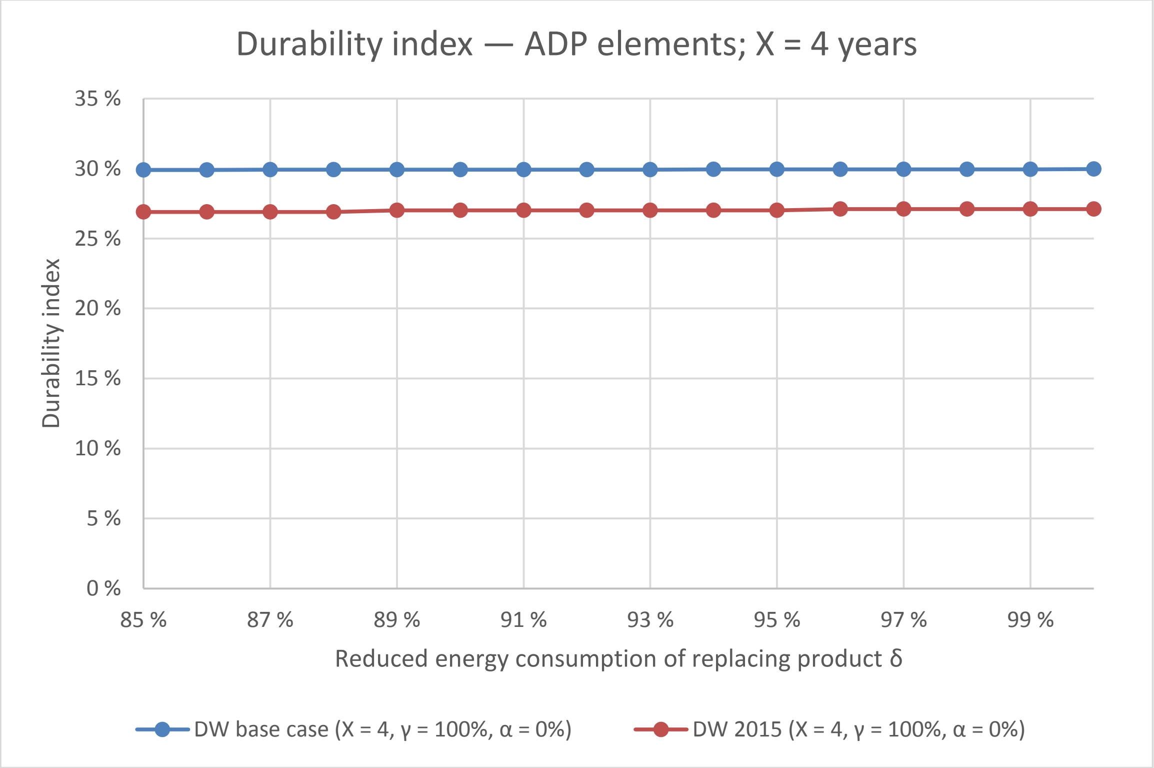


Figure 1.21. Durability index comparison for ADP elements. X = 1 in the upper graph, X = 4 in the lower graph

1.4.10. Conclusion of the DW case study

This section concludes the durability analysis of dishwashers, conducted on an exemplar DW base case to understand what the environmental benefit (or impact) could be that results from the extension of the lifetime of the device. A series of parameters has been included in the analysis: the possibility to have a newer product (B) with higher energy efficiency (parameter δ) and different manufacturing impacts (parameter γ), but also the possibility to have incremental impacts to make the DW base case more durable (parameter α).

Ardente and Mathieux (2014a) proved that the lifetime extension of an energy-using product is always environmentally beneficial when the substituting product (B) has a lower energy efficiency. Therefore, the current analysis assumed and considered more efficient substituting products: the improvement of the efficiency of the substituting product in the use phase has been considered in the wide 0-30 % range, independently of whether these levels are currently achieved by any product on the market.

Initially, the LCA analysis identified the main contributors to the results, for instance the use of electronic components (PCB in particular) during the manufacturing phase and the energy and detergent consumption during the use phase. Even if the present LCA cannot be directly compared to the DW case study (2015) as it is (the two system boundaries are partially different), some relevant considerations can be highlighted: the BoM of the present DW base case has a clear effect on the abiotic depletion of elements, due to the use of zinc, copper, stainless steel and, as previously mentioned, electronic components. The use phases, even if with the same use rate and a similar expected lifetime, were modelled using different hypotheses, especially concerning the energy consumption per cycle. Another source of variability is represented by the specific impact per unit of kWh of electricity, which has recently changed at the inventory level. This change is characterised by an updated energy mix that resulted in a variation of specific impacts between the present and the previous analysis (e.g. the average GWP impact for the EU Electricity mix is 0.473 kg CO_2 eq./kWh, whereas it used to be 0.590 kg CO_2 eq./kWh). The EoL phase of the LCA model does not take into account environmental credits from material recycling.

Concerning the durability analysis, final remarks also depend on the selected impact category in this case. Three impact categories were selected as being representative of the overall set of environmental results: climate change (measured as GWP), abiotic depletion of elements and freshwater eutrophication.

Prolonging the DW base case lifetime produces limited environmental benefits for the freshwater eutrophication. However, freshwater eutrophication is mainly influenced by the impact of the detergent used during the use phase. Thus, durability indexes resulted not very relevant for the freshwater eutrophication (always below + 0.6 % of the life cycle impacts). This assessment was based on impacts of detergents assessed by (Golsteijn et al., 2015). The use of low-content phosphorous could result in the reduction of the freshwater eutrophication impact, up to 90% (JRC, 2016a). This would imply that, even if the same benefits are achieved in absolute terms, these would be more relevant in a life perspective (i.e. having higher values of the durability index for this impact category). Future analyses will explore the possibility of estimating the amount and the type of detergent used during washing cycles and of updating the durability index formula by introducing the variability of impacts for this parameter as well.

Considering the various situations depicted in Sections 1.4.8 and 1.4.8.1, it is possible to confirm that prolonging the lifetime of the DW base case is environmentally beneficial for the GWP indicator in the large majority of the scenarios considered. Excluding relevant variations of the impact to manufacture new products, or incremental impacts to make the product more durable, it is environmentally convenient to prolong the lifetime of the DW when δ (the energy consumption of the newer product (B) replacing the DW base case) is higher than 85 % of the consumption of the base case (Figure 1.14). Accounting for higher variations of impact for manufacturing, the environmental benefit is ensured when the energy consumption of the newer product (B) is not greater than or equal to 95 % of the DW base case (Figure 1.17).

Moreover, for the ADP elements indicator, which is mainly affected by materials used during the production phase, prolonging the DW base-case lifetime was always beneficial. This environmental impact can be reduced by about 45 % when the operating life is extended by 6 years and about 7 % for an extension of 1 year (γ = 100 %, α null). When manufacturing impact variations for the newer product are included (γ equal to 150 %), and excluding incremental impacts to make the DW base case more durable (α null), the two percentages become 69 % and 11 %.

Chapter 2

2. Reusability analysis

This chapter is devoted to the formalisation and analysis of key characteristics of the reuse activities of energy-using products, in particular of white goods such as dishwashers and washing machines. The chapter also includes an exploitation of this knowledge for the development of an environmental assessment method of the reuse of products, suitable for product policies. In particular, we analysed products that, after the end of their first use, are sent to reuse centres (meaning companies active in the reuse of products), which perform a series of treatments necessary for the reuse.

The present analysis is based on studies available in the literature and on information provided by several relevant European reuse centres: the SOFIE[29] facility based in Grace-Hollogne (Belgium) dealing with the disposal and refurbishment of large and small household appliances and furniture; and two facilities of the French federation ENVIE[30], dealing with more than 45 facilities, operating on different types of products, including washing appliances, cooking appliances, cold appliances and electronic equipment. The two analysed ENVIE facilities are based in St Etienne and Lyon (France).

Reuse companies generally operate as social enterprises, providing years of experience and training opportunities in the reuse sector for disadvantaged workers, thereby giving the opportunity to start in the labour market (Rreuse, 2015). They also help people with a low income to have access to affordable essential goods across Europe.

The present analysis focused mainly on two product groups: washing machines and dishwashers. However, to a large extent the studied reuse activities have a general scope and can be related to other product groups. For this reason the discussion also included some information previously collected from other companies dealing with the reuse of electronic equipment (e.g. desktop and laptop computers, servers, electronic displays and copy machines)[31].

2.1. Definitions of reuse

In the waste framework directive the EU defines reuse as ‘any operation by which products or components that are not waste are used again for the same purpose for which they were conceived’ (EU, 2008). Moreover, this directive defines preparing for reuse as ‘checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be reused without any other pre-processing’ (EU, 2008). The main difference between reuse and preparing for reuse is that in the case of reuse the product has not become a waste (European Commission, 2012b). These definitions have also been adopted by the EU WEEE directive (EU, 2012).

The waste framework directive (EU, 2008) does not provide additional specifications on different types of reuse. However, both other pieces of legislation (e.g. the ecodesign directive) and the scientific literature tend to mix the term ‘reuse’ with other related concepts and terms as refurbishing, remanufacturing, reconditioning, etc. Sometimes these terms are used interchangeably.

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[29] http://www.electrosofie.be/collecte-et-tri

[30] http://www.envie.org

[31] A detailed analysis on the reuse of electronic products has been presented in Talens and Ardente (2015).

For example, the ecodesign directive introduced the definition of reuse as 'any operation by which a product or its components, having reached the end of their first use, are used for the same purpose for which they were conceived, including the continued use of a product which is returned to a collection point, distributor, recycler or manufacturer, as well as reuse of a product following refurbishment' (EU, 2009).

Additional definitions have been provided by international ISO standards, such as ISO 16714, which defines reuse[32] as 'any operation by which component parts of end-of-life machines are used for the same purposes for which they were conceived' (ISO 16714, 2008). According to this standard, reuse also includes remanufacturing, defined as the 'process by which value is added to component parts of end of-life machines in order to return them to their original same-as-new condition or better' (ISO 16714, 2008). A similar definition has been provided by standard BS 8887-211 (2012).

Other sources sometimes refer to reconditioning, defined as 'the process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally, the resultant product has a warranty that is less than that of a newly manufactured equivalent' (Optima limited, 2013). Moreover, King and Burges (2005) noticed that 'Reconditioning involves less work content than remanufacturing, but usually more than that of repairing. This is because, unlike remanufacturing, reconditioning only requires the rebuilding of major components to a working condition rather than "as new"; yet, unlike repair, all major components that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components.'

A more detailed discussion on the definition of reuse is provided by the authors in previous studies, such as in Ardente et al. (2011) and Ardente et al. (2015).

As a result, for the analysis discussed in the present chapter, the following definitions are adopted.

- Reuse includes any operations by means of which a product or its components, having reached the end of their first use, are used for the same purpose for which they were conceived. It includes such operations as remanufacturing and refurbishment, where:
    - remanufacturing is the process by which value is added to products or component parts at their end of-life in order to return them to their original same-as-new condition or better (including legal warranties) — remanufacturing is generally performed by original equipment manufacturers (OEM), and mainly applied to business-to-business products;
    - refurbishment (or refurbishing) is the process of returning a used product to a satisfactory working condition — warranties can be granted to refurbished products but these are generally shorter than the legal warranties for new products.

Reuse can concern both products and waste. In the special case where the inputs are products that have been discarded as waste, the term 'preparation for reuse' is adopted.

A further specification is also needed for repair activities, since these are crucial for different product life cycle steps, either before or after the product is discarded after its first use. The present study included an analysis of the repair activities necessary for the product's reuse. On the other hand, repair activities happening before the end of the first use (without change of ownership) are excluded from the analysis. Moreover, the

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[32] Various documents, including ISO 16714, used the hyphened wording 're-use' instead of 'reuse'. However, the latter form is nowadays more commonly used in the literature and has been preferred in this report.

analysis of products fully or partially remanufactured by the OEM for the production of products 'as new'[33] is considered to be out of the scope of the present report.

It is finally highlighted that definitions previously introduced are not necessarily in line with those in the references discussed in the literature review of Section 2.2.

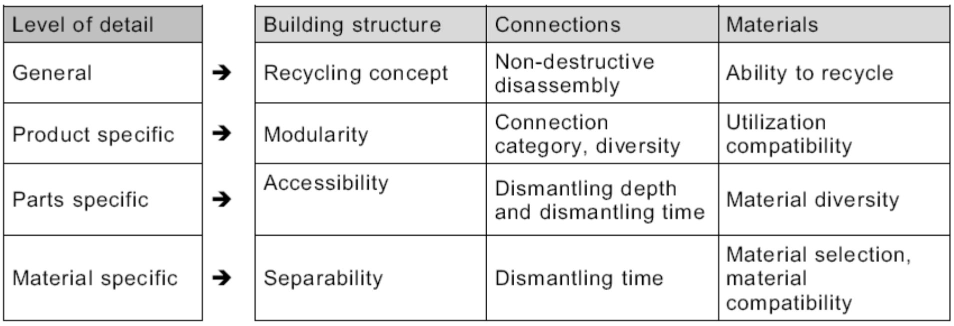
2.2. Standards on reuse of products

Product reuse has mainly been discussed by standards as a general concept. ISO 14021 (1999), for instance, established rules about 'self-declaration claims', including the case of reusable products. However, it did not add specific guidance on the assessment of reusability as a metric. In the last several years a growing interest has been observed on the part of national and international standardisation bodies on the reuse of products. Details of some of these standards and guidelines is provided in the following literature review.

2.2.1. Standard EN 62309

In the European context, the first standard fully devoted to reuse was EN 62309 (2004). The standard describes requisites that products with reused parts should have, in particular the characteristics of the technical documentation for the product containing reused parts, as well transparency requirements for the consumers and methods for the traceability of these products. Among the tools used to meet the needs of EN 62309 (2004), we highlight the possibility to include serial numbers or traceability labels for reused parts. A proper design for reuse ensures that major parts of returned products can be reused, in as many cases as possible. Standard EN 62309 also describes technical issues to be considered when approaching 'design for reuse', including, among the others: modularity; upgradeability; maintainability and accessibility; ease of disassembly; interchangeability; interoperability; testability; robust design for damage.

Table 2.1. Design-for-reuse aspects in relationship with different design pillars (from EN 62309, 2004)



Level of detail		Building structure	Connections	Materials
General	➔	Recycling concept	Non-destructive disassembly	Ability to recycle
Product specific	➔	Modularity	Connection category, diversity	Utilization compatibility
Parts specific	➔	Accessibility	Dismantling depth and dismantling time	Material diversity
Material specific	➔	Separability	Dismantling time	Material selection, material compatibility

Table 2.1 shows relevant aspects of design for reuse and recycling, in relationship with different design pillars such as: 'building structure, connections, and materials' (EN 62309, 2004). For example, general strategies include the use of fastening techniques suitable for non-destructive disassembly. The design of key parts should allow their accessibility and separation, aiming at the optimisation of the dismantling sequence.

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[33] For further details on this topic, see Ardente F, Mathieux F, Talens Peiró L. Revisions of methods to assess material efficiency of energy related products and potential requirements. EUR 28232; doi 10.2788/517101

2.2.2. Standard prEN 50614 (under preparation)

Within the standardisation mandate M/518[34] of the European Commission to European standardisation organisations, standard prEN 50614 is currently under development on ‘Requirements for the preparation for reuse of waste electrical and electronic equipment’. This document focuses on the reuse of electrical and electronic equipment (REEE) or equipment which was previously discarded as WEEE and has been prepared for reuse for the same purpose for which it was conceived. Draft standard prEN 50614 aims, among others, to:

- encourage the reuse of waste electrical and electronic equipment, and reduce recycled or incinerated WEEE;
- provide a framework to assure consumers of the safety of the equipment and the quality of the processes for preparation for reuse;
- assure manufacturers that returning products to the market after preparing for reuse will not adversely affect their brands or the safety reputation of the equipment;
- provide assurance to stakeholders of the legality of operators preparing for reuse.

The draft standard therefore provides a relevant description of quality, safety and environmental requirements that a reuse operator should adopt to support the claim that a WEEE has been prepared for reuse and has therefore reached end-of-waste status according to the waste framework directive (EU, 2008).

2.2.3. Standard BS 8887-211

Standard BS 8887-211 (2012) is titled ‘Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Specification for reworking and remarketing of computing hardware’. This standard analyses the key processes for reuse. Although this standard was developed mainly for the computer product group, the recommendations provided can generally be extended to EEE. According to the standard, reusable products can originate from (Figure 2.1) (BSI, 2012):

- defective products (non-working when first taken out of the box, known as ‘dead on arrival’), or a repair within the warranty period when returned to the OEM, or broken or damaged in transit, etc.;
- factory overstock (where for example a drop in market demand has resulted in excess inventory against current sales activity);
- products used for demonstration or display models;
- products returned because of marking strategies (such as a proof-of-concept trial; comparison testing; a ‘try-and-buy’ offer; a free loan to replace other failed products);
- unused products returned by the customer (e.g. for incorrect order or delivery, remorse purchase or products that did not perform to specification or the required standard);
- used products returned by the customers (including also end-of-lease returns, product traded in against a new purchase).

This standard also highlighted several benefits related to reuse, in particular environmental and commercial benefits. The reuse of a product extends the use of raw materials, resources and energy at the first point of manufacture (BSI, 2012). The repair, refurbishment or remanufacture of a product provides no more than 20 % of the CO_2 emissions compared to manufacturing a new product (BSI, 2012). Moreover, the pricing of remarketed products is lower than that of new products, which is attractive to

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[34] M/518 — Mandate to the European standardisation organisations for standardisation in the field of waste electrical and electronic equipment (Directive 2012/19/EU (WEEE)).

those consumers who do not require the very latest product, have a limited budget and/or are seeking a more cost-effective option.

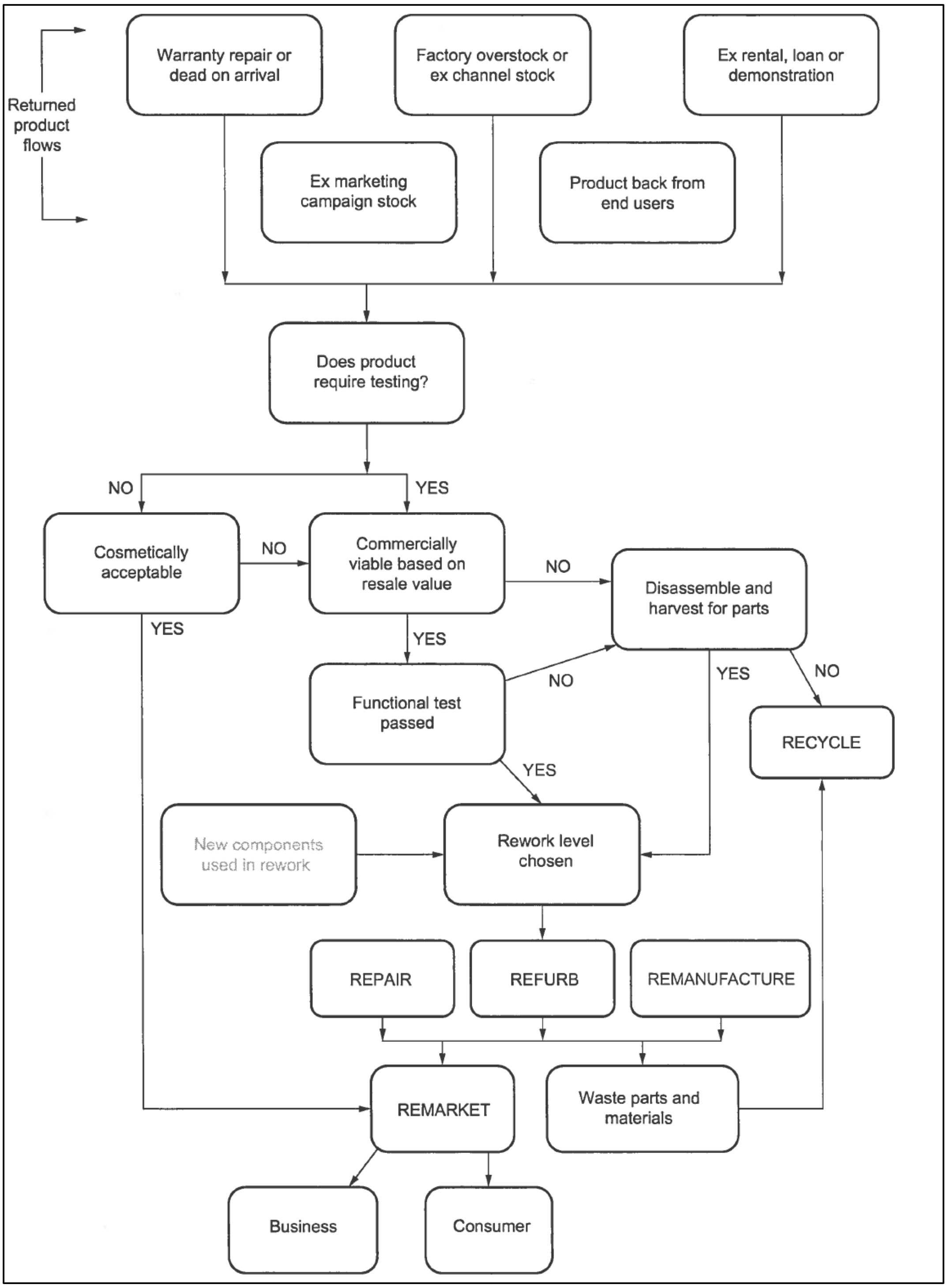

Figure 2.1. Flow diagram on the reuse of products (from BS 8887-211, 2012)

2.2.4. Standard VDI 2343

Standard VDI 2343 (2014) ‘Recycling of electrical and electronical equipment — Reuse’ analyses various crucial aspects related to reuse. First of all, the standard provides different definitions, such as for reuse I (equivalent to the definition of reuse as in the waste framework directive) and reuse II (equivalent to preparation for reuse). Different levels of activities are distinguished in the standard for reuse, such as:

- repair, which restores defective products to their intended state;
- refurbishing, which restores used products to a previously defined quality level;
- remanufacturing, in which products that are 'as good as new' are made through recombination with new and reconditioned components and parts;
- upgrading, which enhances the properties of the starting product, including its function, performance and safety.

It then discusses the potential benefits of the reuse of products, and estimates the functional and economic benefits in comparison, for example, to recycling. 'Reuse conserves the functionality of the equipment or components, and thus the added value generated in the original production … As a result, in many cases the achievable revenues for reconditioned products and components are orders of magnitude higher than those achievable for the recycling of material fractions' (VDI, 2014). 'About the ecological benefits of less use of energy and other resources when avoiding the production of new equipment, need to be seen in the context of the potentially higher or lower operating consumption of comparable new equipment. Usually, reliable statements are possible only after an ecological comparison of the entire life cycles of the alternatives (e.g. new equipment against reused equipment), taking into account various environmental impact categories' (VDI, 2014).

VDI 2343 then explores the German legislation that can be linked to reuse and, in particular, issues related to liability (for damage caused by defective products or components, or for injury to the health of users or the manufacturer's staff) and warranty. 'For reuse it is an important issue whether the original manufacturer continues to be liable or whether or to what extent the reseller becomes liable for damages' (VDI, 2014). The standard states that 'as long as used electrical equipment is reused without modification (reuse I), the manufacturer continues to be liable after it is re-sold … Electrical equipment does not lose its product property automatically by having become waste in the meantime and then placed on the market again … If used or waste electrical equipment is converted for other applications or significantly enhanced performance, a new product … is created. Those carrying out the modifications are subject to their own product liability' (VDI, 2014). In addition, product and manufacturer liability changes when modifications to second-hand equipment are made before its sale for reuse, i.e. 'where it is not only maintained or repaired but its essential properties and functions are affected in such a way that new (damage) risks are created.'

Concerning warranties, the standard clarifies that 'when selling used EEE, material defects involve in the first instance the vendor's liability … The vendor may be e.g. a manufacturer subject to the take-back duty or a waste disposal contractor.' The provision of extra guarantees (beyond the legal requirements) on the reused products can have the effect of reinforcing the conviction on the purchaser of the quality of the products.

VDI 2343 also provides recommendations about the preselection of products with reuse potential. In the future, targeted preselection of reusable products 'should be achievable using automated identification systems (auto-ID systems). With these systems, data are recorded on some appropriate medium (barcode, Radio-Frequency Identification — RFID tag), which then links the information permanently to the product. Readout units (scanners, readers) can pick up this information automatically when the product arrives, and process it electronically. This is done in the form of a standardised, unambiguous numerical code, which digits represent the product's features such as manufacturer (brand), manufacturing date and item type. In addition to the numerical code's information content further disposal-relevant data can be provided (e.g. material composition, pollutants and valuable substances that need to be treated selectively, disassembly instructions)' (VDI, 2014). The standard then discusses in detail various technical and economic aspects related to reuse, and also provides some examples for different EEE.

2.2.5. Standard ONR 192102

Standard ONR 192102 (2006; 2014) is titled 'Durability label for electric and electronic appliances designed for easy repair'. It establishes a label for electric and electronic appliances (white and brown goods) designed for easy repair (Figure 2.2). The standard introduces a set of criteria, subdivided into mandatory (to be followed by anyone claiming the label) and voluntary (to which a score is associated) criteria. According to the number of criteria the product complies with, an overall reparability score is given to the product. Then the overall quality of the reparability is assessed as 'good', 'very good' or 'excellent'. Some examples of criteria for reparability are listed in Table 2.2.

Table 2.2. Examples of criteria for reparability (modified from ONR, 2006)

Criteria	**Reasons**	**Implementation examples**
Essential parts of the product should be capable of being disassembled into individual parts without any special tools. If, nevertheless, special tools are required, they shall be easily available to any repair company (not only those authorised by the manufacturer).	Accessibility of sub-assemblies has to be ensured for the purpose of repair.	Utilisation of commercially available screws. Screwed connections that cannot be detached should be avoided.
The availability of spare parts shall be ensured for a minimum of 10 years after the last batch is produced.	Ensuring long product life.	
Errors recognised by the software should be indicated (on a display or by a flashing LED or code) and their meaning should be described in detail in the instructions for use.	Keeping repair periods to a minimum.	When, for example, the error 'F7' is shown on the display of a WM, the instructions for use should explain that this is, for example, a pumping-out defect.
Regular training on product and service information (organised by the manufacturer at affordable costs) should be accessible for technicians of all repair companies (not only those authorised by the manufacturer).	Ensuring that repairs can be performed by any repair company.	
Availability of instructions needed for repair, including among the others: — Wiring plan, circuit diagram, exploded views, connection scheme, functional description, disassembly plan, program sequence plan, timing, troubleshooting tree, etc. — Instructions on how to	Keeping repair periods to a minimum. Clear understanding of how an appliance has to be disassembled. Making repairs possible. Restoring optimum equipment quality. Ensuring long product life. Optimisation of the appliances' quality.	

Criteria	Reasons	Implementation examples
reset the error codes. — Information on settings required after components or subassemblies are replaced. — Supply directory for spare parts. — Up-to-date information on series defects. — Print diagrams or service prints for circuit boards of brown goods.	Ensuring that repairs can be performed by any repair company (not only those authorised by the manufacturer).	

Figure 2.2. Label for ‘excellent’ reparability of the product (from ONR, 2006)

2.2.6. Publicly available specification PAS 141

Publicly available specification PAS 141 (2011), titled ‘Reuse of used and waste electrical and electronic equipment (UEE and WEEE) process management specification’, was developed to:

- provide a robust framework for the testing, treatment and provision of reused electrical and electronic equipment;
- give reassurance that used equipment is electrically safe to use and functionally fit for purpose;
- allow the original producers of the equipment reassurance that their safety liabilities and reputation are protected, as reuse organisations will have documented processes for safety tests, removal of confidential data and record keeping;
- provide a method of differentiating legitimate exports from illegal exports of WEEE under the guise of being sent abroad for reuse.

PAS 141 represents guidance for setting up a quality management system for organisations dealing with the preparation for reuse of WEEE, complying with environmental, health and safety regulations. Reuse organisations have to prepare their own procedures and protocols appropriate to their activities.

The United Kingdom Waste and Resources Action Programme (WRAP)[35] owns the PAS 141 registered mark. It is a member of the Technical Advisory Committee and hosts the

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[35] http://www.wrap.org.uk/sites/files/wrap/pas-141-operational-diagram.pdf (accessed May 2016).

informative website. WRAP also developed samples of product-specific protocols (PSPs), which are available online[36]. These guidance documents are based on industry experience and highlight the tests and procedures that should be carried out as a minimum. Examples of reuse protocols for some products are illustrated in Table 2.3 and Table 2.4.

The protocols can include additional general suggestions. For example, 'inspection of the cosmetic condition of the equipment should also be performed to ensure that the external casing is not damaged in such a way that could affect the future performance of the product (e.g. a crack in the casing that could lead to degradation of the internal components) … All former user identification (e.g. asset tags, portable appliance test stickers, company logos etc.) should be removed. Manufacturers brand labels and rating plates should not be removed' (WRAP, 2013). 'If any process fails, the unit may require disassembly and/or repair. Identify any hazards, risks and controls before the appliance disassembled to reduce risk. Where replacement components are to be used, they should be OEM replacement components, OEM approved patter components, reclaimed identical components or aftermarket components appropriate for the intended application and purpose' (WRAP, 2013).

Figure 2.3. Certification label for compliance with PAS 141 requirements (WRAP, 2014)

A certification process based on PAS 141 is also set up (WRAP, 2014). A company complying with the requirements of PAS 141 can ask for an audit by an external accredited body to certify their compliance. 'Certifications indicate that a process is in place that provides that received equipment will be handled in a responsible, effective and auditable manner and providing reassurance in the quality of that equipment. Certification does not per se alter the legal status of the equipment; however, it is likely that certification will help a reuse organisation demonstrate to the regulatory authorities that their processed equipment need not be subject to waste management controls' (WRAP, 2014). Certified organisations can also use the related certification label (Figure 2.3).

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[36] http://www.wrap.org.uk/content/benefits-pas-141 (accessed May 2016).

Table 2.3. Product-specific reuse protocol for dishwashers (modified from WRAP, 2013)

Preparation process	**Component to be analysed**	**Test**
Visual inspection	Hoses/trims/connector/seals	Check condition of hoses, trims and connectors. Check door seals for damage.
	Door hinges and handles and detergent dispenser	Visually check the condition of door or lid, handles and detergent dispenser.
	Knobs, switches, internal racks and spray bars	Check to see if there are any knobs, switches, internal racks and spray bars missing or damaged.
	Cabinet and back panel	Examine condition of cabinet and back panel.
	Feet	Check all four feet.
Safety	Plug and lead cables	Examine the plug (insulated) and lead cables.
Function test	Door-locking mechanism	Plug in the machine and start on a preset program. Check the locking mechanism works before the machine begins operating. Check that the locking mechanism stops the machine by opening the door part way through the program.
	Hoses/connectors/seals	Connect all hoses to water supply and check for leaks; include the drain hose. Ensure the hot and cold inlet valves are operating correctly and not leaking (where fitted).
	Program control timer	Fill the dishwasher with clean items and run on a full program at a 'normal' or 'eco' temperature.
	Internal components	Check all internal components etc. originally fitted by manufacturer (such as internal racks) are functioning correctly.
	Thermostat and heating element	Begin a program. Check that the water-heating process begins by opening the door part way through the program.
	Detergent, salt and rinse aid dispensers	Check detergent, salt and rinse aid dispensers and valves. Place detergent, salt and rinse aid in dispensers.
	Wash and rinse phases	Set the machine to run on a short program. The machine should take in water during the washing phase without overfilling, drain the water on completion of the wash phase and take in more water during the rinse phase without overfilling. Listen to check that the upper and lower spray arms are rotating and dispensing water.
	Drain phase	Ensure the water drains after the wash phase and after the rinse phase.
	Dry phase	Following the rinse phase, check that the drying phase begins.
	Outlet pipe/sump/hose	Check outlet pipe for signs of damage and leaks.
	LED display (if applicable)	Check that the appropriate information (clock, cycle number, time remaining, etc.) is shown in the display area.

Table 2.4. Product-specific reuse protocol for washing machines, tumble dryers and washer dryers (modified from WRAP, 2013)

Preparation process	**Component**	**Test**
Visual inspection	Hoses/trims/connectors/seals	Check hoses and trims for signs of damage/tears, etc. and that connectors are undamaged. Check door seals for any damage.
	Door or lid hinges and handles and soap trays	Visually check the door or lid and handles. Soap trays should be present and not cracked.
	Feet/wheels	Check all four feet/wheels.
	Knobs, switches and fixings	Check to see if there are any knobs, switches or fixings missing or damaged.
	Cabinet and back panel	Examine cabinet to ensure that there are no fractures or corrosion.
Safety	Plug and lead cables	Examine the plug (insulated) and lead cables.
Function test	Motor	Check the motor to ensure it operates quietly without excess heat generation.
	Drum/spider	Check drum/spider bearings.
	Door — locking and unlocking	Plug in the machine and switch on. Set to a preset program/cycle and check the door locks. Check the locking mechanism works before the machine begins operating. On completion of the program/cycle, check the lock stays on for a brief period after the machine program has ended.
	Hoses/connectors/seals	Connect all hoses to the water supply and check for leaks; include the drain hose. Ensure the hot and cold inlet valves are operating correctly and not leaking (where fitted).
	Programs	Fill the drum with clean textile items. Run the appliance on a full, non-fast coloured 40 °C cycle. Check drum rotates on wash cycle.
	Internal components, pressure switches, modules and wiring	Check all components etc. originally fitted by manufacturer are present and functioning correctly.
	Thermostat and heating element	Begin a program and ensure that the water heating process begins.
	Detergent dispenser	Check detergent dispenser and valve. Place detergent in dispenser.
	Rinse cycle	Set the machine to the rinse cycle and observe. The machine should take in water during the rinse cycle without overfilling and drain the water on completion.
	Drain operation	Ensure water drains after final rinse.
	Spin operation	The machine may have different spin speeds. Set the control to the different settings and observe if there is a difference. Check that the drum rotates for each setting. Observe the machine (with full load) during fast spin for movement Check the spin rotation and look out for noise, grinding or vibration.
	Delayed start (if available)	Check that the delayed-start feature works by setting the machine to start after a certain period of time.
	Outlet pipe/sump hose	Check outlet pipe for signs of damage and leaks.
	Drying cycle	Fill the machine with damp textiles and set the temperature control to its highest setting.
	Filter (if available)	Open filter compartment and check the filter.
	Timer	Set the drying timer to run for a certain period of time.
	Sensor drying (if available)	Check that the sensor drying feature works by selecting the function.
	Condenser system	Visually check that the condenser in a washer/dryer is producing water.

2.3. Attitudes of Europeans towards reuse

This section briefly summarises the findings of the recent report presented by the European Commission on the 'Attitudes of Europeans towards waste management and resource efficiency', with a special focus on the reuse of products (European Commission, 2014). The longevity of products is recognised as one of the most relevant aspects for EU citizens' perception. When buying a durable product (such as a washing machine or a dishwasher), the most important factors considered by survey respondents were: low running costs due to improved energy efficiency; the take-back program by which sellers take old products when supplying the new one; and finally the durability of the product.

Furthermore, a remarkable willingness to purchase second hand products was also identified. About 44 % of European citizens would buy second-hand electronic equipment and about 37 % a household appliance. These percentages vary greatly between EU Member States, with the highest willingness shown in Spain, Portugal and the United Kingdom. A more positive attitude towards the reuse of products is demonstrated by young people and people with higher education.

It is also interesting to understand the reasons for not buying second-hand products. About 43 % of respondents in this group stated that the (perceived) lower quality of the products prevents them from buying second-hand products, while 41 % are concerned about health-and-safety issues. A fifth of surveyed people said that second-hand products usually look less appealing (20 %), while a similar proportion indicate that they have never thought of buying anything second hand.

The survey then investigated whether the respondents had tried any other alternatives to buying new products, such as a remanufactured product defined as a 'used product whose faulty or old components have been replaced, enabling the product to be resold with the same guarantees as a new item'. It was found that about a third of respondents (35 %) had already bought a remanufactured product. Moreover, roughly a quarter of respondents (27 %) used sharing schemes (including sharing of cars or bikes) and a fifth of people (21 %) leased or rented a product such as a washing machine instead of buying it. Respondents who answered that they had never bought a remanufactured product were then asked what prevents them from doing so. A majority of people (52 %) in this group answered that they prefer to buy new products, while four out of ten (39 %) answered that they are not confident in the quality of remanufactured products. A third of respondents (33 %) have never bought a remanufactured product because the option was not available in their area, and three out of ten people (31 %) answered that they had never heard of remanufactured products.

These figures demonstrate that large shares of EU citizens are in favour of reused products. This aptitude is more evident for some product groups, including energy-using products. However, there are some aspects that need to be improved. First of all, citizens should be informed of the availability of refurbished/remanufactured products and the related environmental, economic and social benefits. Moreover, consumers need to be assured of the trustworthiness of reused products, being aware of the treatments and the quality control which products undergo and the warranties provided.

2.4. Main processes for the reuse of products

As indicated in the introduction to this section, this section is based on visits to and the analysis of three representative reuse centres, one based in Belgium, and two based in France. While the SOFIE (Belgium) facility was recommended by a manufacturer, the ENVIE facilities in France were recommended by the Rreuse organisation.

According to all the facilities visited, the activities for the reuse of EEE can be subdivided into three steps (Table 2.4):

- logistics — includes all the activities to deliver the product to the reuse centre after the end of its first use;
- refurbishing — includes all the treatments on the product to bring it into a satisfactory condition for selling;
- commercialisation — includes all the activities for the sale and post-sale servicing.

These steps will be described in detail in the following sections.

Figure 2.4. Steps for the reuse of products (modified from ENVIE, 2015)

2.4.1. Logistics for the reuse of products

Logistics includes all the activities necessary to supply the reusable products to the refurbishing facility. This step is of utmost relevance since its main objective is to deliver a sufficient number of products of an adequate quality. The incorrect handling of the equipment generally causes unnecessary damage, which leads to it being discarded, even if it was qualitatively good at the end of its first use and with good potential for reuse.

Concerning transport, each company applies its own procedures to optimise the amount of transport, reduce the routes and ensure the safety of the product and the workers. The implementation of a quality management system and/or an environmental management system usually contributes positively to the success of this phase.

The transport can be operated by the companies themselves or by third parties. It was noticed that companies can have preferences for some sources of used products (e.g. retailers, manufacturers, municipal collection schemes, consumers) according to their experience of the quality of the used products previously delivered.

For example, one thing of particularly interest is the ‘reverse logistics’ programme applied by SOFIE together with a white-goods manufacturer. In this case, the manufacturer takes care of collecting the used appliances together with new appliances when these are delivered to the small retailers[37], distributed in the territory. The discarded appliances are then collected in the logistic facilities where new products are stored and, after an initial screening, reusable appliances are sorted and sent to SOFIE for the refurbishment treatments. The manufacturer also implements a continuous flow of information in order to provide the reuse centre with all necessary information for the repair. This programme provides several benefits, including: optimisation of transport and reduction of the related impacts (the overall amount of transport is almost halved); the reusable equipment is carefully handled until its delivery to the refurbishing facility (since the reusable equipment is handled together with new products); careful pre-checking of the used products (which allows delivery to the reuse centres only of

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[37] Big retailers generally implement their own systems to handle used products.

products of a quality sufficient for reuse); proper repair of the product (for the correct functioning of the product and the safety of operators and users).

Logistics also includes the task of identifying products with a higher potential for reuse. The product is subjected to one or more visual inspections by operators. Each reuse centre applies different procedures for this checking and selection, according to their business model. However, some general common criteria have been observed:

- preference for products belonging to the medium-average market share (products belonging to the low market segment are generally discarded upon reception);
- preference for more recent products;
- preference for products that are clean and aesthetically in good condition, and avoidance of products with evident scratches, dents, damage or missing parts;
- predilection for some particular brands, according to local user preference in that area;
- predilection for some particular brands that are judged by the reuse centre to be more durable and more suitable for refurbishing (including the preference for products of which the company has good experience in terms of reparability and spare-part availability);
- demand from the shops selling the refurbished products (taking into account also the availability of refurbished products, seasonal fluctuations and the variability of preferences by customs).

Checklists and specific training courses are generally provided to help the operators in this selection. The checklists can be used when the product reaches the refurbishing facilities or even earlier, before transport. It is clear that the sooner serious problems on the product are identified the better it is. When a product is found not to be compliant with the selection criteria, it is discarded and diverted to the waste flow.

Refurbishment can also involve products that have not been used but that suffer from a failure or defect upon commissioning (e.g. products damaged during delivery or substituted during the warranty period). Generally, these products are included among those with the highest reuse potential. Products that meet the criteria are considered ‘reusable’. These are weighted and labelled or codified (to allow their traceability).

2.4.2. Refurbishing treatments

Once in the workshop for refurbishing, reusable products are subjected to additional checks. Criteria similar to those previously described (like preference for products that are recent, clean and aesthetically in good condition) are applied. The product undergoes a more accurate check, including exterior and interior parts, performed by specialised operators, who also try to estimate time and costs for the necessary interventions, as well as the availability of spare parts. Considering spare parts in particular, they could be new components purchased from manufacturers or used spare parts extracted from WEEE and stored in warehouses. The operator is also in charge of judging the level of deterioration of key parts of the product. Products that pass this check undergo the following steps.

The product is plugged in and, when necessary, connected to the water, gas and waste water lines. Then some basic tests are performed to check the main functions of the product and its safety, according to company’s checklists. For example, the initial testing on a washing machine focuses on (ENVIE, 2015):

- locking/unlocking of the door;
- filling and filling stop;
- engine rotation;
- heating of the washing bath and temperature control;

- emptying of the tank;
- spinning.

The checking of the appliances may be supported by technical information, the availability of which is considered crucial in this phase. For example, the ENVIE facilities used the 'Agora'[38] platform, created for after-sales services related to household appliances, and this facilitates the exchange of information between manufacturers and repairers. This tool was exclusively intended for professional repair and maintenance operators. Alternatively, other manufacturers provide information through their websites, but this information was not always easily accessible by independent repairers and reuse centres.

When failures or damages are detected, more accurate testing is performed. Reuse centres have generally developed tests and procedures for this purpose. For example, ENVIE developed a simple piece of software available on touchscreen computers at the workshops that guides the operator through a step-by-step identification of the problems (Figure 2.5).

Certain failures can imply the substitution of faulty parts with spare parts. These can be original components (purchased from the original manufacturer or within the stock of reused components at the reuse centre) or adapted from components by other manufacturers. If the repair of the product is judged too difficult, too expensive or not possible, there is still the chance that at least some components could be disassembled and stored in the company's warehouses for the refurbishment of other products. The reusable components are sorted, with a preference for:

- components that are more frequently substituted;
- components that are known to be expensive;
- components that are crucial for the external appearance of the products.

Components that are typically disassembled to be reused are as follows.

- For WM: control panel with electronic board, switches and display; door seal; handles; engine; heater and thermostat; drain pump and pump filter; detergent trays; hoses.
- For DW: control panel with electronic board, switches and display; circulation pump; heater; spray arms; hoses; dish racks.

In some cases, key parts are preventively substituted to avoid future failures. This can be the case for drain pumps (in WM and DW) or motors and belts (in WM).

After checking and repair, the products undergo full cleaning and cosmetic checking. This phase is generally the most time consuming, and it has been highlighted as particularly relevant for the customer safety (to avoid biological risks) and because it affects the appearance of the product and, therefore, its saleability. As a matter of fact, even if users are aware of the possibility of purchasing used products, they are not keen on having products with evident signs of wear. Therefore, for reuse centres, it is really important to try to restore the product as close as possible to its original appearance. In the case of large white goods pressurised water with cleaning agents is used, while for electronic devices dry cleaning is performed. During cleaning, the operator takes care to remove signs (such as traces of paint or labels put on by the users) and detect cosmetic deficiencies that require additional repair or the replacement of some parts. This phase may be very expensive because of the costs of labour or spare parts, and can lead to the conclusion that a product should be discarded because it is not adequate for the market (Culligan and Menzies, 2013).

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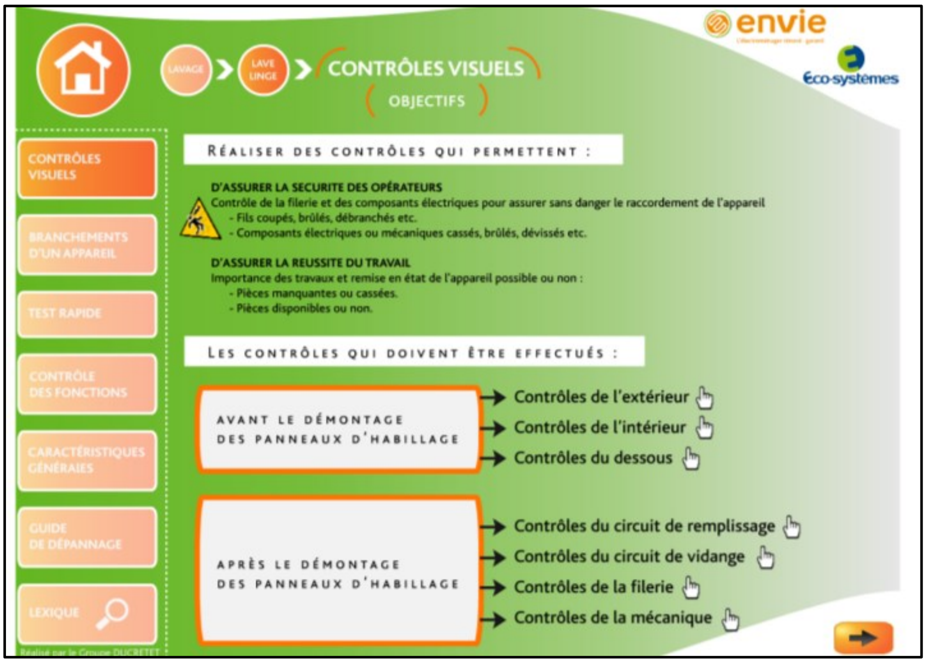
[38] http://www.agoraplus.com

The last step of the refurbishment consists of the quality check. This implies the following.

- Testing of the functions and programs. In some cases, when the characteristics of the products are modified, the power consumption is also measured.
- Overall aesthetic inspection, including the check on the presence and correct appearance of all the parts (including accessories).
- Product labelling (for sale) with information concerning the main characteristics of the product (brand, model, main features) and price.

A procedure generally applied by all the reuse centres consulted is the compilation of a product information sheet with all the details of the interventions performed on the products. After completing the refurbishment, the product information sheet is electronically achieved in a database, allowing the management and the traceability of all of the activities, from the arrival of the appliance in the workshop to the following-up of after-sales actions.



RÉALISER DES CONTRÔLES QUI PERMETTENT :

D'ASSURER LA SECURITE DES OPÉRATEURS
Contrôle de la filerie et des composants électriques pour assurer sans danger le raccordement de l'appareil
- Fils coupés, brûlés, débranchés etc.
- Composants électriques ou mécaniques cassés, brûlés, dévissés etc.

D'ASSURER LA REUSSITE DU TRAVAIL
Importance des travaux et remise en état de l'appareil possible ou non :
- Pièces manquantes ou cassées.
- Pièces disponibles ou non.

LES CONTRÔLES QUI DOIVENT ÊTRE EFFECTUÉS :

AVANT LE DÉMONTAGE DES PANNEAUX D'HABILLAGE
→ Contrôles de l'extérieur
→ Contrôles de l'intérieur
→ Contrôles du dessous

APRÈS LE DÉMONTAGE DES PANNEAUX D'HABILLAGE
→ Contrôles du circuit de remplissage
→ Contrôles du circuit de vidange
→ Contrôles de la filerie
→ Contrôles de la mécanique

Figure 2.5. Screenshot of software developed to support the checking of the products during refurbishment at the workshops (modified from ENVIE, 2015)

2.4.3. Sales, services and warranty

The sale and provision of service is the last part of the refurbishment, and it is fundamental, since the target of all the previous activities is to meet clients' expectations.

First of all, sale can occur in various forms. Some companies are based on their own networks of selling points distributed throughout the territory and potentially supported by e-commerce. Other companies use commercial agreements with external local retailers. In addition, some companies also act as spare-parts providers for other external repair companies and reuse centres.

The sale price is generally lower than an equivalent new product (generally 30-40 % of a new or similar product). The price depends on the characteristics of the products, such as the age, the brand, the general conditions and the outcomes of the tests during refurbishment.

Also, the target clients can be very different, depending on the product group, such as:

- consumers — people in economic difficulties and people sensitive to the social and environmental finalities of the company;
- companies, mainly for 'business-to-business' products such as servers and copy machines;
- other reuse centres, purchasing spare parts.

According to communications with the reuse centres, new consumers are nowadays more and more common, due to the effect of the economic crisis and being attracted by the low prices of the products. People can have prejudices about reuse centres, in addition to a reluctance to purchase a product used by somebody unknown. Knowledge of the quality procedures enforced by the reuse companies and direct observations of the standardised treatments by trained operators during refurbishment could be an incentive for purchasing.

The reuse centre is also fully liable for the treatments they performed and a warranty is applied to all refurbished products. However, the length of the warranty is variable and can range from few days (e.g. for small appliances) up to 1 year (including labour and spare-parts costs). The reuse centre can provide also some extra services, such as delivery, home assistance and an extended guarantees. These services can be provided for a fee or free of charge, depending on the product and the client.

In some case it was noticed that the company marked the product with signs or labels. This has the aim of making it evident that the product is a reused product and increasing the visibility of the company (Figure 2.6). The products are also sold with booklets for use and maintenance, as developed by the reuse centre.

Figure 2.6. Exemplar label developed by a reuse centre to identify refurbished products and attached to the front of them

2.5. Flows of reused products

According to the companies visited (SOFIE and ENVIE) the flows of reused products are very different.

In the case of SOFIE, it was reported that in 2014 about 3 770 devices were initially selected from waste coming into their facility for refurbishment. Around 2 695 units with an overall mass of 135.3 t (mainly washing machines, dishwashers and fridges, with an average mass of 50.2 kg per device) were successfully refurbished. Refurbished devices represented about 2 % of the overall flow of devices annually handled by SOFIE. Around 90 % of the refurbished products were sold in 2014. However, this doesn't mean that the demand for refurbished products was lower than the availability of refurbished products, but rather that demand is more focused on higher-quality products (10 % of unsold products were mainly products belonging to the low market segment). Therefore, it is recognised that there is a need to focus in the future on the refurbishment of products belonging to higher market segments. Moreover, according to the company, the average refurbishing rate is of about 1.2 device per person per day. This corresponds to about 90 workers per 1 000 tonnes of WEEE refurbished/reused[39].

ENVIE is the largest French federation of reuse centres. According to information from ENVIE, 93 873 appliances were refurbished and sold in 2015: 78 715 (84 %) were big appliances (including washing machines, dishwashers and washer dryers) and 15 158 (16 %) other products (including small appliances, flat screens, computers). Products were sold via a network of around 45 shops distributed throughout France. Used products for refurbishment are provided thanks to an agreement with the French WEEE collection schemes, for example Eco-systèmes. In 2015 refurbished washing appliances (washing machines, dishwashers and washer dryers) at ENVIE had an overall mass of 1 640 tonnes. Considering the most up-to-date statistics, 260 170 tonnes of WEEE large household appliances are treated annually in France (data referring to 2013[40]). Assuming roughly that washing appliances (e.g. washing machines, dishwashers and washer dryers) were 60 % of this amount, it is estimated that washing appliances refurbished by ENVIE amounts to about 1 % of WEEE washing appliances treated annually in France. Moreover, according to Rreuse (2015), ENVIE reported 649 employees managing 18 341 tonnes of WEEE annually, with a rate of around 35 jobs per 1 000 tonnes of products refurbished.

2.6. Issues observed in the reuse of washing machines and dishwashers and discussion on potential product features

Based on the discussion with the reuse centres, some criticalities for the reuse of washing machines and dishwashers have been identified.

2.6.1. Legal boundaries for products, waste and waste prepared for reuse

An evident concern about the unclear regulations for reused products and reusable waste emerged during the interviews with the reuse centres. Although this topic is strictly based on the interpretation of the current legislation and goes beyond the purposes of the present chapter, it is mentioned since it represents, according to the people interviewed, one of the major barriers to the development of reuse activities.

As mentioned before, the main difference between 'reuse' and 'preparing for reuse' is that in the case of 'reuse' the product has not become waste (European Commission, 2012b). However, it is of utmost importance to state when waste ceases to be such. In fact, after that point the waste regulations no longer apply to refurbished appliances. The reuse operator shall then take into consideration the product regulations.

According to Rreuse (2015b), in some Member States the waste directive has been interpreted in such a way that it is impossible to reuse a product once it became waste. Therefore, it is necessary to specify when a WEEE becomes a REEE. It is here recalled that the criteria for waste to cease to be waste are as follows (EU, 2008)[41]:

(a) the substance or object is commonly used for specific purposes;

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[39] Assuming 230 working days per year, and an average mass of 50.2 kg for the devices.

[40] Eurostat, 2013 (from http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do; accessed in June 2016)

[41] According to Rreuse (2015b), 'EU waste policy must be more flexible and help facilitate and encourage the possibility to re-use goods once they have become waste. This is currently a major legal obstacle in some Member States where once products become waste, it is legally impossible to re-use them. Therefore, reaching "end of waste status" must be possible following a preparing for re-use process, not only following a recycling process and clarification of this is needed in Article 6 of the EU Waste Framework Directive.'

(b) a market or demand exists for such a substance or object;
(c) the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;
(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts.

Similarly, it is under debate to what extent reused products should comply with the EU's harmonised legislation for products, including, for example, requirements set by the EU ecodesign directive. In this case, the most accredited interpretation is that remanufactured products, i.e. products brought up to the condition 'as new', should comply with all the requirements for new products (European Commission, 2016). In particular, the EU Blue Guide established that 'The Union harmonisation legislation applies to newly manufactured products but also to used and second-hand products, including products resulting from the preparation for reuse of electrical or electronic waste, imported from a third country when they enter the Union market for the first time … A product, which has been subject to important changes or overhaul aiming to modify its original performance, purpose or type after it has been put into service, having a significant impact on its compliance with Union harmonisation legislation, must be considered as a new product … Products which have been repaired or exchanged (for example following a defect), without changing the original performance, purpose or type, are not to be considered as new products according to Union harmonisation legislation … Such repair operations are often carried out by replacing a defective or worn item by a spare part, which is either identical, or at least similar, to the original part (for example modifications may have taken place due to technical progress, or discontinued production of the old part), by exchanging cards, components, sub-assemblies or even entire identical units. If the original performance of a product is modified (within the intended use, range of performance and maintenance originally conceived at the design stage) because the spare-parts used for its repair perform better due to technical progress, this product is not to be considered as new according to Union harmonisation legislation. Thus, maintenance operations are basically excluded from the scope of the Union harmonisation legislation … Software updates or repairs could be assimilated to maintenance operations provided that they do not modify a product already placed on the market in such a way that compliance with the applicable requirements may be affected.'

Additional guidance on these issues could be crucial to promote reuse within the EU, as for example the requirements to be set by standard prEN 50614 (under development, see Section 2.2.2 for further details).

Concerning other relevant legislation, Spain was recently the first European country to require a specific percentage of waste prepared to be reused . The new Spanish Royal Decree (No 110/2015) requires that, starting from 2017, 2 % of large household appliances collected as WEEE and 3 % of IT equipment collected as WEEE is to be prepared for reuse; the targets will rise to 3 % and 4 % respectively starting from 2018 (Spanish Royal Decree, 2015). In addition to these targets, the new Spanish rules also include, among others, the following requirements (Rreuse, 2015).

- Improve the monitoring, traceability and supervision requirements of waste management activities by the public administration.
- Separate collection, transport and storage conditions to allow appropriate preparation for reuse and to prevent breakages and loss of materials. For instance, collection points are required to have a space dedicated to reusable goods.
- Recognise the role of social-economy actors in waste collection and treatment and the possibility of handing over WEEE to these entities. The rules also establish the requirements for the preparation of reuse centres and installations so they can carry out verification, separation and repairing activities, etc.

- Give local authorities the possibility to include social clauses in public contracts and partnerships to allow social-economy actors priority access to waste management activities.
- Users may be able to deliver WEEE directly to the preparation for reuse centres or the WEEE may be checked and sorted in WEEE collection facilities.
- Competent authorities shall announce the list of centres authorised for preparation for reuse.

These strategies are in line with EU waste legislation, which puts reuse, together with waste prevention, at the top of the list of preferred options. Moreover, these strategies would contribute to increasing the availability of reused products to meet the high demand from EU citizens, as discussed above.

Specific product requirements (such as safety or environmental requirements) should also apply to a refurbished product. However, a refurbished product cannot be comparable, in terms of performance, to the newest products on the market and it would not always be in line with the latest changes in the regulations on the product (especially for products with a long average life). For example, Worrell and Reuter (2014) noticed the potential issue of reusing products containing hazardous substances. On the one hand the waste framework directive (EU, 2008) is pushing for the reuse of waste as the preferred option, on the other hand regulations such as REACH (EU, 2006) currently restrict the use of certain substances, including a ban on substances previously largely used in products available on the market and now approaching the end of their lives. On this debate a 2013 judgment of the Court of Justice of the European Union is also recalled, in which it ruled that 'European Union law does not, as a matter of principle, exclude the possibility that waste regarded as hazardous may cease to be waste … if a recovery operation enables it to be made usable without endangering human health and without harming the environment' (EU, 2013).

2.6.2. Issues related to identification, separation and transport processes for reusable products

First of all, the reusable products need to be carefully transported and delivered in good condition. This aspect is relevant for all products, both large household appliances, due to their dimensions and handling difficulties, and small appliances, since these are generally very fragile and stored in inappropriate conditions for reuse at the collection points. As observed in some WEEE collection plants, sometimes products that are initially reusable are handled without much care, and are damaged irreversibly.

It is clear that the transport of used devices cannot be as careful as for new products, especially since the used products are often irremediably broken, exhausted or incomplete and are handled as waste for recycling. However, such practices also compromise products that still have potential for reuse. This potential loss generally already occurs at the early stages of collection, such as at the retailer or at municipal collection points. We highlight the need to build cooperation between the various actors, such as municipalities, retailers, collection schemes, reuse centres and manufacturers. Access to used products by reuse organisations needs to be granted at an early stage of collection, either by collective schemes or directly by municipalities or other operators, such as retailers (Seyring et al., 2015). Criteria and checklists, developed by the reuse centres and used for the selection of reusable products, could be shared with other operators working in the supply chain of the used products in order to identify reusable products early. Once identified, these products could be sorted and sent via dedicated transport channels. Moreover, the examples of cooperation between the reuse centres and the original equipment manufacturers for the logistics (e.g. via common reverse logistic systems) or with the national collection schemes for WEEE, as discussed before, could be strengthened and extended to other European contexts.

Also, consumers should be incentivised to report reusable products (e.g. products still working, in generally good condition) when these are replaced. Products that have potential for reuse should be brought by the consumer directly to the reuse organisation to ensure the reuse potential is preserved (Seyring et al., 2015). In general, all the actors involved in the collection of products, including retailers, should be rewarded financially for the materials and products which they separate for preparation for reuse in order to incentivise and enforce this activity (Rreuse, 2013).

Requirements to improve the quality of logistics for reuse could be promoted by standardised good practices for WEEE (see e.g. the WEEE labex[42] project) and by EU legislation. For example, the WEEE directive could require that used products, before being sent for recycling/recovery, are checked for possible reuse. The setting of separate targets for preparation for reuse[43] has been proposed during the policy discussion for the WEEE directive (Seyring et al., 2015). The policy discussion also included the analysis of potential opportunities and threats relating to separate reuse targets (Table 2.5).

Table 2.5. Opportunities vs threats of having separate targets for reuse within the EU WEEE directive (modified from Seyring et al., 2015)

Opportunities	**Threats**
— Resource savings — High potential for job creation — Consumer demand	— Risk of double counting (WEEE might be collected and prepared for reuse several times). — Need to report separately the flows of reused products. — Costs for changing the organisation of the sector (ensuring proper storage, transportation, etc.). — Availability of spare parts to prepare WEEE for reuse. — Lack of data to estimate the real potential of reuse. — Distortions to reach the target and producers taking ownership of reuse. — Design of products improving unequally. — Specific requirements applying to reuse organisations. — Inability of some Member States to reach the target.

2.6.3. Linking reuse with reparability

The WEEE directive has recognised the relevance of 'encouraging the design and production of electrical and electronic equipment which take into full account and facilitate their repair, possible upgrading, reuse, disassembly and recycling.' Similarly, the ecodesign directive included, among the parameters to be focused on in the preparation of product's requirements, the 'extension of lifetime' as expressed through minimum guaranteed lifetime, minimum time for availability of spare parts, modularity, upgradeability and reparability.

On this topic, the recent European Commission communication on the circular economy stated that, 'Currently, certain products cannot be repaired because of their design, or because spare parts or repair information are not available. Future work on ecodesign of products … will help to make products more durable and easier to repair: in particular, requirements concerning the availability of spare parts and repair information (e.g. through online repair manuals) will be considered' (European Commission, 2015). Similar considerations have also been reiterated by the abovementioned Spanish Royal

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[42] http://www.weeelabex.org

[43] More than 70 000 t of WEEE was reported by Member States to Eurostat as being reused and prepared for reuse in the EU in 2012. This represents 2 % of WEEE collected in the EU-28 (Seyring et al., 2015).

Decree (2015), which prescribed the need for easily repairable and reusable products, as well as the requirement for producers to provide the necessary information to prepare reuse centres in order to enforce this (Spanish Royal Decree, 2015).

The aspect of the reparability of products was also related to the concept of 'economic obsolescence' in a recent report by the German Ministry for the Environment (Prakash et al., 2016). According to this study, economic obsolescence 'is related not only to the technical possibilities of carrying out repairs, but also to the availability of repair service and especially incurring repair costs. Appreciation of costs between product replacements and repairs is in most cases the key factor for decisions pertaining to repairs and crucial for changing useful service life of products' (Prakash et al., 2016).

All these pieces of legislation and studies converge with the opinion of the centres for reuse that were interviewed that reparability is one of the crucial aspects for reuse. The promotion of reparability passes through various potential strategies, such as:

- facilitate the diagnosis of the product;
- accessibility and ease of disassembly of key components;
- availability of spare parts;
- update/upgradability of components;
- provision of information.

All these strategies are essential, and need to be developed at the same time. It could be, in fact, that spare parts are available, but their substitution is too long/difficult to be economically viable. Alternatively, electronic components could be available and easy to replace, but if the program update would be infeasible or would be too expensive, all the efforts for repair would be nullified. Above all, transparent, clear and detailed information is necessary for all the key steps for repair. It should be accessible to professional repairers (both professional and independent) and to refurbishing operators. These strategies will be described in detail in the following sections.

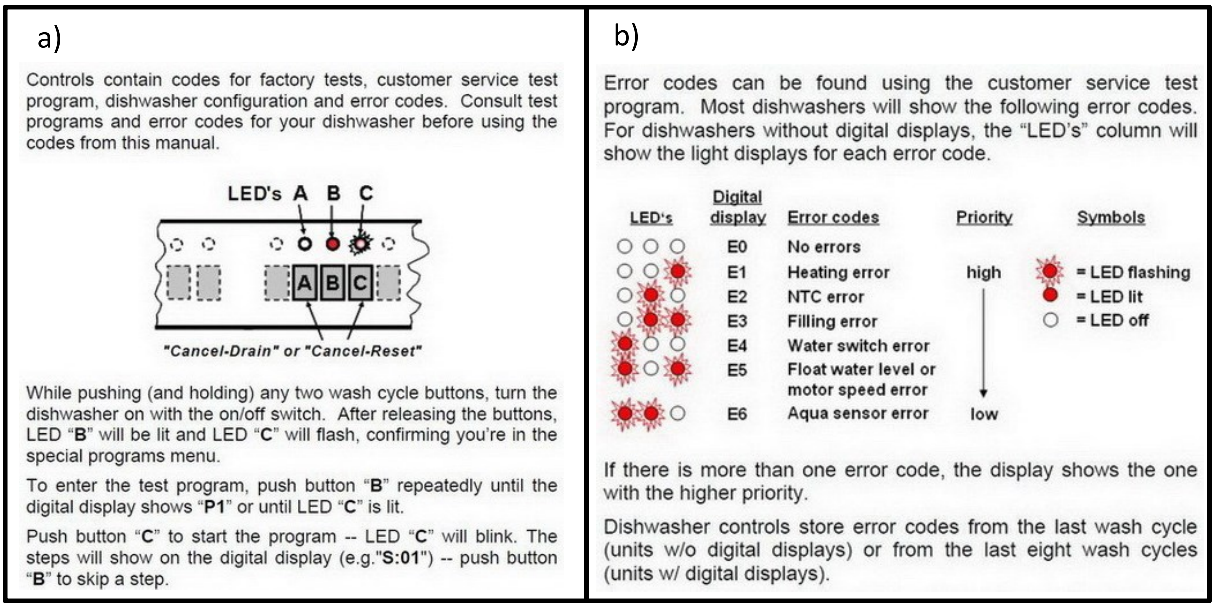
2.6.3.1. Facilitate the diagnosis of problems

The identification of problems and failures in products is the first necessary step in order to solve them. This identification can be carried out with careful analyses, tests and appropriate procedures. On the other hand, manufacturers are increasingly developing and implementing automated systems (e.g. test cycles), which can be used as a troubleshooting measure. The sharing of information about these systems may simplify the testing of the appliances and therefore contribute to reducing the time and costs for the refurbishment.

Generally, the start of these diagnosis systems in WM and DW necessitates a particular combination of switches to be activated and/or movements of the manual selector (e.g. see Figure 2.7). Then, when the test identifies a failure, an error code is displayed and associated with a specific problem encountered. When an LCD display is present, the error code is shown directly on the display. Otherwise, the machine returns a combination of lit LEDs corresponding to the error code (see Figure 2.7(b) as an example).

Information about the use of diagnosis systems and the interpretation of error codes may be part of user manuals when there is no safety risk for the consumer. In some cases this information is provided through the websites of manufacturers or repair associations. In others it is provided by special tools available on the market (e.g. through the abovementioned Agora platform or similar). However, in some cases access to this information is restricted to authorised service partners, which makes difficult, or even impossible, their use by independent operators specialised in the repair and refurbishment of products (R.U.S.Z, 2015). Also, when available, information from different manufacturers can be quite heterogeneous, and the detail or clarity is not always sufficient (including problems relating to translation into different languages). In some cases the erasure of the error codes is impossible to be performed by independent reuse/repair centres (R.U.S.Z, 2015).

The availability of procedures to run and interpret the test/diagnosis programs in DW and WM could support repairers and reuse centres. Although the standardisation of procedures and codes is difficult, due to the large variability of the devices, it is worth displaying this information in standardised formats. In addition, other relevant information could be included, such as suggestions on how to proceed to solve detected faults.



a)

Controls contain codes for factory tests, customer service test program, dishwasher configuration and error codes. Consult test programs and error codes for your dishwasher before using the codes from this manual.

While pushing (and holding) any two wash cycle buttons, turn the dishwasher on with the on/off switch. After releasing the buttons, LED "**B**" will be lit and LED "**C**" will flash, confirming you're in the special programs menu.

To enter the test program, push button "**B**" repeatedly until the digital display shows "**P1**" or until LED "**C**" is lit.

Push button "**C**" to start the program -- LED "**C**" will blink. The steps will show on the digital display (e.g."**S:01**") -- push button "**B**" to skip a step.

b)

Error codes can be found using the customer service test program. Most dishwashers will show the following error codes. For dishwashers without digital displays, the "LED's" column will show the light displays for each error code.

LED's	Digital display	Error codes	Priority	Symbols
○ ○ ○	E0	No errors		
○ ○ ✹	E1	Heating error	high	✹ = LED flashing
○ ✹ ○	E2	NTC error		● = LED lit
○ ✹ ✹	E3	Filling error		○ = LED off
✹ ○ ○	E4	Water switch error		
✹ ○ ✹	E5	Float water level or motor speed error		
✹ ✹ ○	E6	Aqua sensor error	low	

If there is more than one error code, the display shows the one with the higher priority.

Dishwasher controls store error codes from the last wash cycle (units w/o digital displays) or from the last eight wash cycles (units w/ digital displays).

Figure 2.7. (a) Example of procedure to run the test/diagnosis program for a dishwasher; (b) Examples of error codes displayed on a dishwasher without a liquid crystal display [44].

2.6.3.2. Accessibility and ease of disassembly of key components

As highlighted by the recent Commission communication on the circular economy, a better design can make products more durable or easier to repair, upgrade or remanufacture (European Commission, 2015). In particular, accessibility and ease of disassembly are crucial aspects of the design, as also highlighted in previously discussed standards such as EN 62309 (2004), ONR (2013) and VDI (2014).

Since repair is mainly performed manually, improving access to and disassembly of crucial components implies a reduction in the time required for the operation and therefore the repair costs. On the other hand, if the time required for the disassembly is too high, the refurbishment of the product could turn out to be no longer economically convenient, even if the product has good reuse potential.

Some of the problems raised by operators of reuse centres are described below.

Ease of disassembly. It is crucial that the component to be repaired can be disassembled, meaning that it is possible to reversibly unfasten and reassemble the component without damaging it and/or the other parts of the device. For this reason, screws, bolts and snap-fits are generally the preferred types of connectors for repair

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[44] http://removeandreplace.com/2015/10/09/bosch-dishwasher-error-codes-how-to-clear-what-to-check/ (Accessed May 2016)

operations; on the other hand, soldering, sealing and gluing are generally not reversible connections. Moreover, soldering during repair is generally more complex and expensive, due to the need for specific technologies (e.g. soldering of refrigerant circuits). Technicians reported the importance of reaching all (or most) of the relevant parts from one side of the device, which will simplify the disassembly and repair the machines.

An example of components with a low propensity for disassembly, often cited by repairers and reuse centres, is bearings in washing machines[45]. Bearings are crucial parts of the machine since they are subject to stress and wear. Failures of bearings can be caused by the unlevelled positioning of the machine or an excessive load with imbalance, which wears out the machine components. Malfunctioning bearings results in loud noises or breaks, eventually causing the main failure of the whole product. The failure of bearings is also one of the most common problems encountered in WM, and one of the main reasons to discard the product. Different design options were observed in our analysis, concerning the fastening of the bearings to the tub and the design of the tub itself. In a number of cases, machines are manufactured with a sealed washing unit in which bearings are fixed to the plastic tub (single, as in Figure 2.8(a), or two-pieces tub, as in Figure 2.8(c)) and cannot be easily disassembled/replaced. Moreover, the replacement of the bearings sealed to the plastic tub is considered a difficult task by repair operators, as it is significantly time consuming, it requires the disassembly of almost the whole machine and, additionally, when not properly performed it can cause future failures of the machine (due to potential misalignment of the bearings [46]) . For some machines with bearings moulded to the plastic tub, replacement is not possible at all; in these cases, it is still possible to substitute the whole 'washing unit' (drum, tub, bearings) when a failure occurs. However, in the case of a single-piece plastic tub costs for repair are very high and generally not economically viable. In the case of a two-pieces plastic tub the cost of the replacement of the bearings plus the rear part of the tub are expensive but still economically viable (ranging from 300€ to 700€, including labour). In other cases, bearings are fastened to a metallic tub (Figure 2.8(b)), making the replacement and alignment of bearings more reliable (lower risks of deformation of the tub). In this case, the replacement of bearings can be economically convenient (around 200€, including labour). In conclusion, the replacement of sealed bearings in the machine's tub is a critical task that can cause ae machine to be discarded. However, according to one of the interviewed reuse centres, sealed washing units could be more resilient to wear and limit breakages. Otherwise, it was observed the design of machines manufactured in such a way that bearings are fixed with screws to the plastic or metal tub, for both horizontal and vertical load machines (although more frequently observed for the vertical load machines with plastic tubs Figure 2.8(d)). In this cases, disassembly and replacement of bearings is easier and not expensive [47].

Accessibility of key parts. The parts that are most frequently disassembled for replacement or repair should be easily accessible. Moreover, it should be possible to disassemble these parts without excessively moving and stressing the machine. For example, not all dishwashers are designed to facilitate access to their circulating and drain pumps. Figure 2.9(a) presents a case where the pumps are located at the bottom of the machine and can be disassembled easily after removing the front frame. This is not the case for the machine in Figure 2.9(b), in which the pumps are hidden by other components and frames and can be accessed with difficulty only from the side, after turning the machine upside down.

Use of special tools. It should be possible to disassemble the products with standard tools, meaning those generally used by the operators dealing with repair or reuse. The

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[45] Bearings are mechanical elements able to minimise friction between moving parts of the device and able to constrain relative motion to only the desired direction.

[46] https://www.youtube.com/watch?v=XaFF2-Rl8Nc

[47] https://www.youtube.com/watch?v=y9p7eH48ws8

use of proprietary tools should be avoided in principle, because it hinders disassembly or makes it impossible. Manufacturers should specify in the technical documentation any special tools that are needed for disassembly. Special tools should be available to any repair company (not only those authorised by the manufacturers)[48].

Design facilitating reassembly. In some cases the disassembly of the product can be easy, while reassembly can be very difficult. To decrease fabrication costs, plastic components are sometimes clipped, with a risk of being broken during disassembly and reassembly. In some cases screws also tend to be easily damaged after being disassembled. One good practice that was observed was the design of WM with a spare space for screws to be used during the reassembly of the components (see e.g. the double-screw system in Figure 2.10(b). This fastening is preferable to a single-screw system (Figure 2.10(a)) because even when one fastening breaks the component can still be reassembled by using the second fastening. However, only a few examples of this good practice exist nowadays.

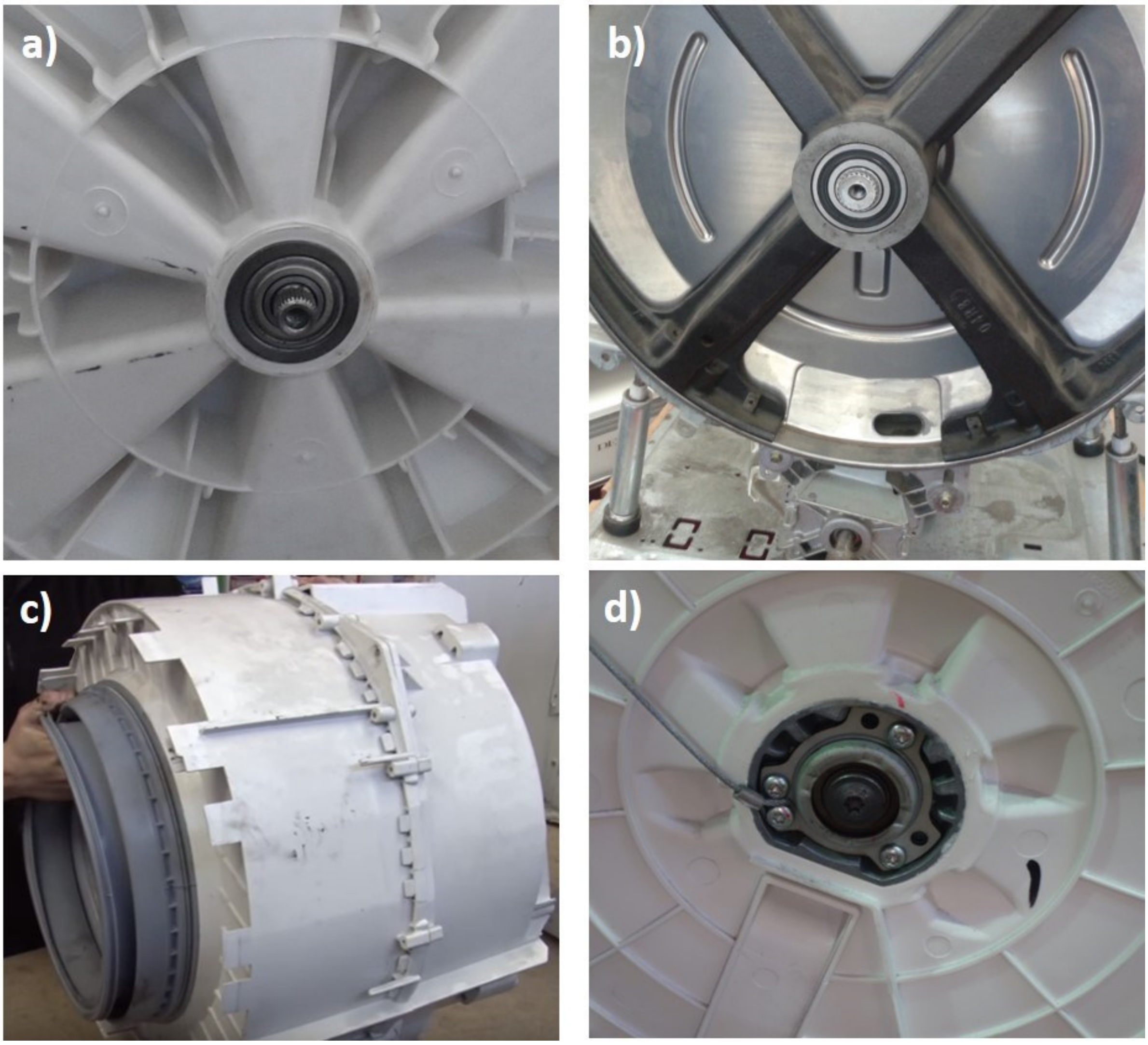

Figure 2.8. Examples of different design for WM bearings: (a) sealed in a single piece plastic tub; (b) sealed in a metallic tub; (c) example of a 2-piece plastic tub; (d) fastened with screws to a plastic tub (vertical load machine).

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[48] These criteria are also in line with the recommendations of ONR 192102 (2013).

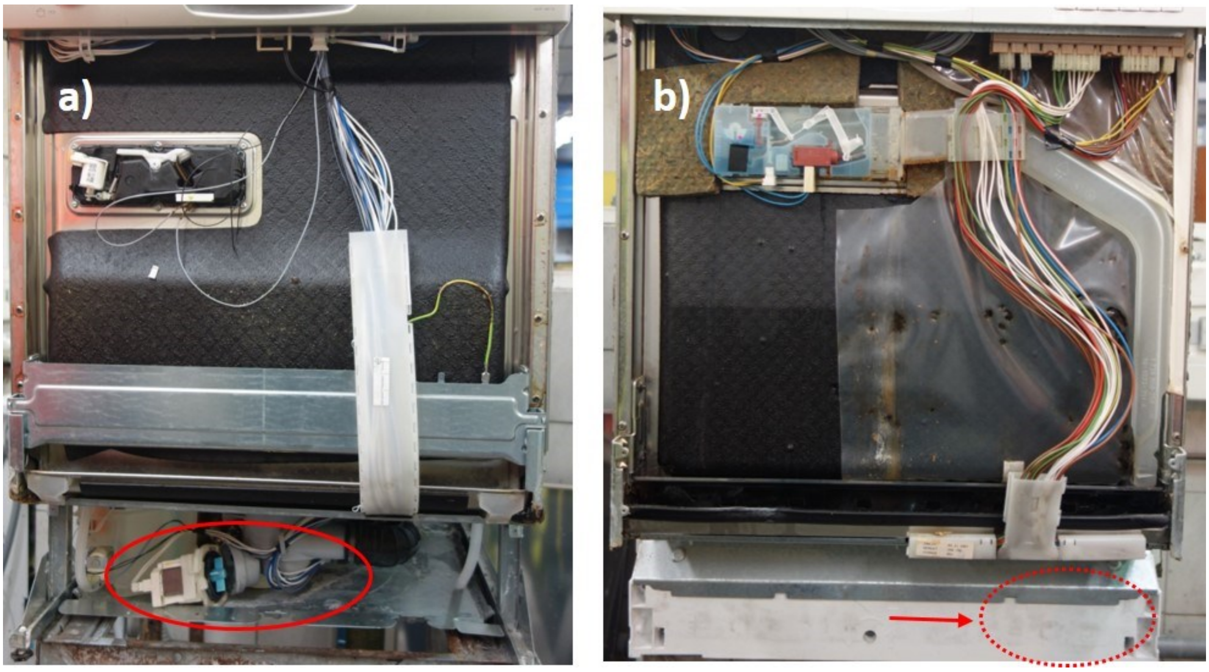

Figure 2.9. Accessibility to dishwasher pumps: (a) easy access; (b) difficult access.

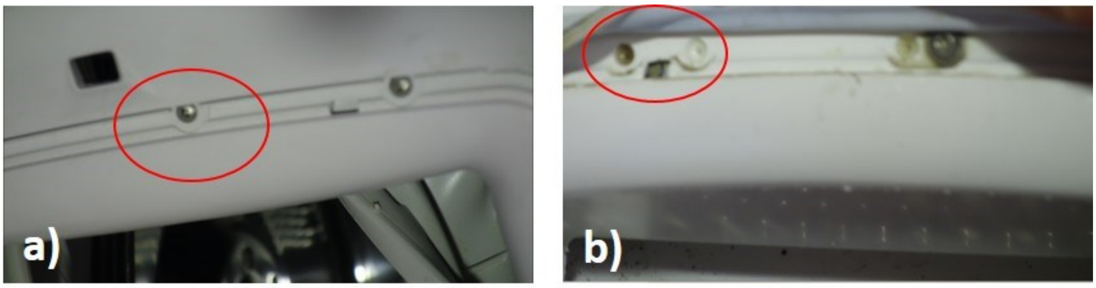

Figure 2.10. Examples of fastening: (a) single-screw system; (b) double-screw system.

2.6.3.3. Availability of spare parts

According to the repair and reuse centres interviewed, the insufficient availability of spare parts is one of the main obstacles to repair. This was also recognised by national standards (ONR 2014) and surveys among repair operators (BIOis 2016)[49]. The repair sector, especially the independent repair sector, is not able to get all the spare parts needed, and this may also sometimes happen during the guarantee period.

One possible reason for this is that some producers provide spare parts to after-sale workshops only if a certain turnover is reached. Moreover, high distribution costs can influence the availability of spare parts. The cost of spare parts in some cases is too high and, together with labour costs, they make the repair of the appliance economically infeasible.

Some manufacturers only supply replacement parts to their approved technical services (BIOis, 2016). At the same time, manufacturers are not obliged to guarantee the availability of spare parts or other relevant materials or services over the whole life cycle

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[49] Based on a survey of 10 000 repair partners of a German repair network, BIOis (2016) identified that the availability of spare parts is the biggest problem for small and local repair shops (retail and independent workshops).

of products, although some manufacturers do that in order to ensure the maintenance and repair of their products (BIOis, 2016).

According to the repair centres interviewed there is a large amount of variability in the approaches adopted by manufacturers for the provision of spare parts, and it is difficult to generalise. Sometimes they have had very different experiences, with spare parts being easily accessible for some models of DW and WM but not for others, even those from the same manufacturer. In some cases the spare parts were available but at very high prices, which makes repair not economically convenient. In other cases it was difficult or even impossible to find out if spare parts were available or not.

Legislation could contribute to making spare parts available, and also to aligning the different attitudes of manufacturers. The ecodesign directive mentions in Annex I the availability of spare parts as one of the parameters to be taken into account when assessing a product's potential for the improvement of durability. Criteria on the availability of spare parts have been also included in the regulation on the EU Ecolabel for several product groups (e.g. European Commission, 2007 and European Commission, 2011).

The availability of spare parts has also been introduced as a requirement by the French government with the French consumption law of 17 March 2014[50]. According to this law, product retailers have to inform the customer about how long spare parts will be available for the products on the market (BIOis, 2016). In this way consumers can make their purchase choices regarding the possibility of repairing their products if needed after a certain amount of time.

The need for spare parts can be partially satisfied by the harvesting of waste products. WEEE that are not suitable for reuse can still be a valuable source of spare parts. The trading of spare parts between reuse centres and repairers can be also promoted by specialised platforms, such as the aforementioned Agora, to facilitate the supply and demand of parts.

Finally, it was observed that some components (such as PCBs) from the same producer can be used for several models of appliances. This design solution greatly facilitates the replacement of the components and the reuse of the product.

2.6.3.4. Update/upgradability of components

Another major issue that often arises when refurbishing WM and DW, as well as other EEE, relates to the checking and programming of the PCB. In some cases, even when some reusable spare parts are available (e.g. from formerly discarded waste), they cannot be used as not properly configured for the refurbished product.

Software updates are mainly used to correct bugs and avoid the replacement of the whole circuit board. Updates can also be crucial in terms of the energy efficiency of products. For example, in the case of microcontroller-regulated WM, upgrading the control software results in reductions in energy, water and detergent consumption, reaching levels comparable to new devices (VDI 2343, 2014).

Therefore, it is important that manufacturers provide specialised operators with tools and systems to allow the easy programming of the circuit board. The cost of this service is very variable and, when too high, can represent a barrier to the repair/reuse. A non-exhaustive list of examples of good practices observed at the refurbishing facilities includes the following.

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[50] http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000028738036&categorieLien=id

(a) Use of a diagnostic tool for checking and reprogramming electronic cards from several models of appliances and that can be used in various products with the same type of chassis (Figure 2.11(a)).
(b) Use of computer-aided service tools that can be installed in personal computers that allows the quick diagnosis of appliances and the creation of spare electronic boards (Figure 2.11(b)).
(c) Use of a smart reader connected with a smart card containing the setting file. The setting reader is connected to the main board for programming. The card is single use and, once the download is completed, must be thrown away (Figure 2.11(c)).

There are many advantages in using these service tools, including the possibility to diagnose the appliances in less time and in a more precise way, thus reducing the amount of spare components required to fix the problem and the time of intervention. Moreover, in some cases, it is possible to create spare electronic boards starting from generic boards with a programming and configuration procedure. This function ensures that the spare part is created in the same way as it was originally produced in the factory.

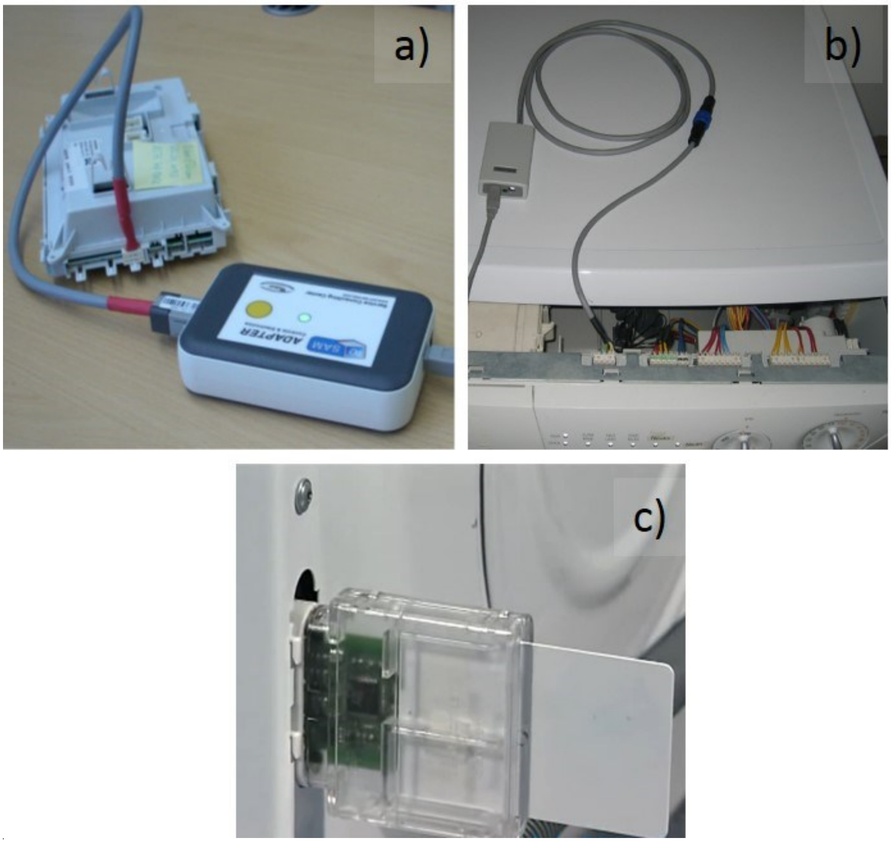

Figure 2.11. Different systems for PCB programming: (a) adapter connected to PCB (from eSAM, 2015); (b) adapter directly connected to a washing machine (from Electrolux, 2012); (c) smart reader connected to washing machine (from Indesit, 2012)

2.6.3.5. Provision of information

Particularly interesting is the provision of information for repair as already regulated for other products (see e.g. Box 1 relating to access to repair and maintenance information for vehicles (EU, 2007)). Several of these points are also relevant for the reuse of EEE and could be introduced in already existing legislation (e.g. in the requirements laid down by the WEEE directive or ecodesign implementing measures). Among these we highlight the recognition of the group of independent repairers as playing a key role in the automotive sector as well as in the repair of EEE.

Box 1. Provision of information for repair

(Extracted from Regulation (EC) No 715/2007 on type approval of motor vehicles.)

Article 3. Definitions.

'"vehicle repair and maintenance information" means all information required for diagnosis, servicing, inspection, periodic monitoring, repair, re-programming or re-initialising of the vehicle and which the manufacturers provide for their authorised dealers and repairers, including all subsequent amendments and supplements to such information.'

'"independent operator" means undertakings other than authorised dealers and repairers which are directly or indirectly involved in the repair and maintenance of motor vehicles'.

Article 6.

'Manufacturers shall provide unrestricted and standardised access to vehicle repair and maintenance information to independent operators through websites using a standardised format in a readily accessible and prompt manner, and in a manner which is non-discriminatory compared to the provision given or access granted to authorised dealers and repairers. With a view to facilitating the achievement of this objective, the information shall be submitted in a consistent manner … Manufacturers shall also make training material available to independent operators and authorised dealers and repairers.'

The repair and maintenance information shall include, among others:

- '…
- service handbooks;
- technical manuals;
- component and diagnosis information …;
- wiring diagrams;
- diagnostic trouble codes (including manufacturer specific codes);
- the software calibration identification number applicable to a vehicle type;
- information provided concerning, and delivered by means of, proprietary tools and equipment'.

Article 7.

'Manufacturers may charge reasonable and proportionate fees for access to vehicle repair and maintenance information covered by this Regulation; a fee is not reasonable or proportionate if it discourages access by failing to take into account the extent to which the independent operator uses it.'

According to the refurbishing operators interviewed, the quality of the documentation provided is quite heterogeneous, even for different products belonging to the same manufacturer. A first potential problem concerns the relevance of the documentation: some of the documents provided can be relevant for manufacturing but not for repairers;

on the other hand, information relevant for repair is sometimes missing. Moreover, documents are not always complete and/or legible (including poor-quality pictures or documents missing some parts). Based on information collected by refurbishing operators and information from the literature, as discussed in this chapter, relevant documentation to be provided includes:

- the product’s exploded diagram with a clear list of referenced parts;
- disassembly information, including the description of the fastening and the necessary tools and operation needed;
- wiring diagrams and connection diagrams;
- a list of test/diagnosis programs and error codes;
- technical notes including the list of potential failures and suggested technical actions;
- the availability of spare parts (and reference number, if necessary), and indicative price.

The availability of additional information, such as user manuals or information on the energy label, can be useful for the sorting and for the sale of appliances. Naturally it is desired that this information would be available in the language of the country where the products are sold.

Moreover, some manufacturers already provide regular training courses on the service, maintenance and repair of their product. These training courses (and associated documentation) should be accessible for technicians of all repair companies.

This information can be provided to the repairers and refurbishing operators through the manufacturer’s website (as generally already done by big manufacturers) or through a technical hotline from the producer, or shared via dedicated platforms (such as the above mentioned Agora). This last option can also simplify the identification and management of relevant documents from several different manufacturers.

2.6.4. Product selling

Product selling is the last and, in economic terms, most important part. Particularly relevant is the provision of information and reassurance to the client about the quality of the device, overcoming some natural concern and barriers in relation to the purchasing of reused products.

Some of the critical aspects in this phase are as follows.

- Liability and warranty. As also discussed by standard VDI 2343, concerns about liability generally cause manufacturers to be reluctant to refurbish their products. Moreover, clients can be concerned by the quality of reused products, and ask for guarantees. Both the reuse centres visited provide refurbished products with a warranty, varying from 6 months to 1 year for large household appliances (WM, DW, fridges, tumble dryers, cooking appliances) to a few days or months for small appliances. Extra guarantees (up to 1 year) can be offered against the payment of a fee covering all costs, such as labour, spare parts and transport.
- Availability of information for clients. User manuals are not easily available for the reused product, especially for those already off the market. To deal with this lack of information, reuse centres have developed general user manuals for each product group. Availability of information on the product also includes the labelling, for example the energy label classes. Some operators suggested having the energy class, and possibly other relevant technical information, directly marked on the product. This would support the commercialisation of reused products.
- Recognition of the status of refurbished product. As highlighted in Section 2.6.1, the boundary between products, waste and waste prepared for reuse are still not

clearly defined by the legislation. Clarity in this sense has been highlighted as a priority. Products prepared for reuse should belong to a separate product category, in which they are clearly separated from waste but, at the same time, they are not under the same requirements as new products.

- Traceability of reused products. This is essential to be able to monitor a product in its different uses. In particular, also for liability issues, it should be possible to understand which operators refurbished the product. Some examples of labels for refurbished products have been developed for companies (see e.g. Figure 2.6) or standardised systems (see e.g. the label in Figure 2.3). Reuse centres could also enforce suitable management systems that allow a certain level of quality, for example keeping a record of all products refurbished by the company and of all the work performed on them. The requirements of PAS 141 or the requirements under development by prEN 50614 may be very helpful for this objective. In particular, it is relevant that reuse centres develop a unique equipment identification number for REEE, linked to a product record containing information such as the manufacturer's rating plate, brand, serial number, and model and product type. The traceability of the reused product is also essential in order to grant sufficient transparency to the clients.

A final observation relates to the limited knowledge of clients relating to the processes for reuse. As discussed in Section 2.3, there is great willingness on the part of EU citizens to reuse products. However, this willingness does not correspond to an established aptitude in purchasing them, mostly because citizens are not aware of reuse centres and reused products. In some cases citizens, even if aware of reuse centres, are not aware of the quality of their processing and the overall quality of the reused products. Scientific analysis, such as the present report, together with informative campaigns by different stakeholders (e.g. associations of consumers, associations of reuse centres, NGOs, public authorities, etc.) can positively contribute to these objectives.

2.7. Environmental assessment of the reuse of products

This section introduces a new method for the assessment of environmental benefits of reuse scenarios of products, such as the one described in Section 2.4. The method is based on previous work related to the environmental assessment of durability (see Section 1 of the report and also Ardente et al. (2012) and Bobba et al. (2015)) and adapted to the reuse context. The method aims at assessing, depending on various parameters (e.g. lifetimes; impacts of production, use and end-of-life phases) if (and to what extent) environmental benefits are produced when the lifetime of a product is extended by reuse (following preparation for reuse operations).

2.7.1. Environmental assessment of a single reuse

For the environmental assessment of the reuse of an energy-using product[51], two scenarios are considered (Figure 2.12):

- the 'standard use' scenario, where the product (A), after its first use, is discarded[52] and substituted by the new product (B).
- the 'reuse' scenario, where the product (A), after its first use, undergoes a series of treatments for the reuse and is reused for a 'second life'.

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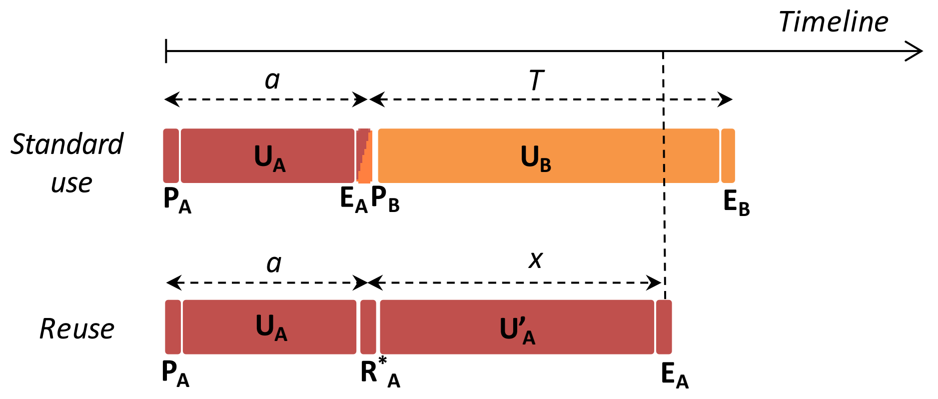
[51] The method was specifically developed for energy-using products. However, this could be extended to the assessment of other products, including energy-related products.

[52] Multiple reasons can determine the discarding of the product, such as failure, damage or willingness to replace with a new product.

The time of the first use of product (A) can be equal to the average life of the product or lower (in case of early failures of the product or user's willingness to discard)[53].

Products (A) and (B) considered in this analysis are not necessarily the same as considered in section 1.2.3.



Symbols:
- P_A = impact of the production of product (A) [impact];
- P_B = impact of the production of product (B) [impact];
- E_A = impact of EoL of product (A) [impact];
- E_B = impact of EoL of product (B) [impact];
- R^*_A = impact of the refurbishment (A) [impact];
- U_A = impact of using product (A), during the first use [impact];
- U'_A = impact of using product (A), after reuse [impact];
- U_B = impact of using product (B) [impact/year];
- a = time of the first use of product (A) [year];
- x = time of the reuse (A) [year];
- T = average lifetime of the replacing product (B) [year].

Figure 2.12. Scenarios for the assessment of the reuse of a product

The term 'R*' groups together all the impacts related to the refurbishment of the product, including, for example, the impacts due to transport to the reuse plant, the product's checking for failures, repairs and spare-part substitution, final testing, cleaning and final transport to the user.

Provided that 'u_A', 'u'_A' and 'u_B' are the impacts per unit of time due to the use of the products, it results that:

$$U_A = u_A \cdot a$$

$$U'_A = u'_A \cdot x$$

$$U_B = u_B \cdot T$$

It is assumed that the life span 'x' is lower than or equal to the average lifetime 'T'. The environmental impact of the two scenarios for the time frame (a + x) can be calculated as follows.

Impacts of the 'standard use' scenario[54]:

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[53] The cases when the time 'a' of the first use of the product are longer than the average lifetime can be considered as an assessment fall-back into the assessment of durability of products. For further details, see Ardente and Mathieux (2012) and Bobba et al. (2015).

$$I_{st\_use} = P_A + U_A + E_A + \frac{P_B}{T} \cdot x + \frac{U_B}{T} \cdot x + \frac{E_B}{T} \cdot x$$

Impacts of the 'reuse' scenario:

$$I_{reuse} = P_A + U_A + U'_A + R^*_A + E_A$$

The difference in the impacts between the two scenarios is calculated as:

$$\Delta_{reuse} = I_{st\_use} - I_{reuse}$$

In particular, it results that:

$$\Delta_{reuse} = \left[\frac{P_B}{T} + \frac{E_B}{T} + (u_B - u'_A)\right] \cdot x - R^*_A \qquad \text{with } x \leq T.$$

The reuse of products implies some environmental benefits when $\Delta_{reuse} > 0$.

The term u'_A was introduced to differentiate the impacts due to the consumption phase of the product (A) after reuse. A product, in fact, could have a performance loss over its lifetime, causing higher energy consumption for example. The difference between the performance of a new product compared to the performance after reuse can be especially relevant when the time of the first use is significantly long. The performance change can also be related to potential failures that cause the end of the first use.

It is also highlighted that the reused product could have the same impacts during use (i.e. $u'_A = u_A$), or even a better performance and therefore lower impacts (e.g. $u'_A < u_A$). This would be the case for a product upgrade performed during refurbishment (e.g. the upgrade of the control software for washing machines, as mentioned by VDI 2343). In general, this potential change in performance is largely dependent on the product considered, on the duration and characteristics of the first use and also on the subsequent refurbishment.

The variation in consumption after reuse can be expressed as a percentage of the initial consumption, as:

$$u'_A = \varphi \cdot u_A \qquad : \qquad \varphi > 0$$

Where:

- $\varphi < 1$ implies that the performance of the reused product is improved (upgraded);
- $\varphi = 1$ implies that the performance of the reused product is maintained;
- $\varphi > 1$ implies that the performance of the reused product is subject to a decay.

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[54] The values $\left(\frac{P_B}{T}x\right)$ and $\left(\frac{E_B}{T}x\right)$ represent the proportion of the impacts for the production and EoL of product (B) for the time 'x'.

The value of 'φ' is considered constant for this case study and first methodology development. When specific information on the dynamic behaviour of the product is available, more complex functions could be evaluated (e.g. φ varying linearly over time)[55].

It should finally be mentioned that the benefits of reuse can be normalised to the life cycle impacts of the product to better describe their relevance. The previous formulas can therefore be modified as:

$$\Delta^{*} = \frac{\Delta_{reuse}}{Life\ cycle\ impacts}$$

2.7.2. Assessment of a single reuse under different situations

As a general simplification, it is assumed that the manufacturing (and analogously the EoL)[56] impacts of product (A) are equal to those of product (B). In symbols, this results as follows: $P_A = P_B = P$; $E_A = E_B = E$. These assumptions are more likely to occur when the time of the first use is not too long and when big technological changes did not occur. The previous formula can be written as follows:

$$\Delta_{reuse} = \left[\frac{P}{T} + \frac{E}{T} + (u_B - \varphi \cdot u_A)\right] \cdot x - R_A^{*}$$

It is highlighted that this formula has a comparable structure to that used for the assessment of the extension of the lifetime of product (Ardente and Mathieux, 2012). However, there are some differences between the terms. First of all, the impact of refurbishment can be different from that of normal repair occurring during the operation (due to extensive replacement of parts, with particular care also for the appearance). Moreover, the factor 'x' in the previous formula can have larger variation ranges compared to the extension of the lifetime as assumed in the analysis of durability. The duration of the time frames of the two uses (i.e. 'a' and 'x') can affect product efficiency (i.e. u'_A). It has also been noted that the impacts related to the first use of the product do not affect this balance, since they were assumed to be the same in the two scenarios. However, the duration of the first use 'a' should be extended by avoiding any type of early failure of the product and generally encouraging the design of durable products, as discussed in Ardente and Mathieux (2012) and Bobba et al. (2015).

Based on the analysis of reuse, as described in the previous paragraphs, some specific reuse situations are discussed, with the related assumptions and potential simplifications of previous formulas.

First of all, some definitions are provided for the three different reuse situations.

1. Reuse situation 1 – product reused after a relatively short first lifetime: the time of the first use is null, or in any case smaller than that indicated by the standard warranty. This situation occurs when, for example, a product suffers damages during the transport, or major failures during the warranty time. In these cases, a product can still be repaired and reused rather than being discarded. Products

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[55] Future research could explore how the performance of the product changes over time, and which functions better address the change in the device.

[56] A generic assessment can also be performed when it is assumed that impacts of production of product (A) differ from those of product (B). In this case, a factor 'α' could be introduced, expressing the impacts of (B) as portion of the impact of (A). In symbols: $P_B = \alpha \cdot P_A$. For further details, see Ardente and Mathieux (2012) and Bobba et al. (2015).

reused in this situation have generally a higher value and, therefore, are preferred by reuse centres.

2. Reuse situation 2 – product reused after an intermediate first lifetime: the time of the first use is higher than a 'relatively short time', but smaller than the expected average lifetime. This situation regards products that already passed the warranty time, but still not reached their expected average lifetime. In this situation, the products generally suffered some failures that the user decided not to repair (e.g. because too expensive). However, it is worth for the reuse centre to undergo repair treatments and allow the product to be operative for some additional years.
3. Reuse situation 2 – product reused after an average first lifetime: the time of the first use is comparable to that expected by the client and by the manufacturer for a given product group. In this case, the product accomplished its expected service life. In case the product experienced some failures that the user did not want to repair (e.g. because of the age of the product). However, the product can be still treated by the reuse centre to allow a longer service life.

Reuse situation (1): product (A) lasts for a 'relatively short time' (e.g. due to damages during the transport or to early failures)

Assumptions:

$a \approx 0$	first use of product (A) very short (or null);
$u_A = u_B$	replacement product (B) has the same energy consumption as (A);
$\varphi = 1$	the performance of the reused product is the same as a new product;
$x \approx T$	reused product (A) will have second life lasting for the average product life 'T'.

It results that:

$$\Delta_{reuse} = (P + E - R_A^*)$$

In this situation there are some environmental benefits when $(P + E) > R_A^*$, namely when the impacts of the refurbishment are lower than the impacts of producing and disposing of a new replacement product.

Reuse situation (2): product '(A) has an 'intermediate duration' below the average lifetime of product group (e.g. due to failures that are too expensive to be repaired)

Assumptions:

$u_A \approx u_B$ replacement product (B) is assumed to have the same energy consumption as (A)(i.e. the potential substituting product in the market does not have significantly better performance).

It results that:

$$\Delta_{reuse} = \left[\frac{P}{T} + \frac{E}{T} + (1 - \varphi) \cdot u_A)\right] \cdot x - R_A^*$$

In this situation, there are some environmental benefits when:

$$\left[\frac{P}{T} + \frac{E}{T} + (1 - \varphi) \cdot u_A)\right] \cdot x > R_A^*$$

This means that reuse is convenient if the product did not suffer a major loss of efficiency and if the impacts of the refurbishment are low. Moreover, the longer the time of the second use 'x' is, the higher the benefits are. If $x \to T$ (i.e. when the reused product has a 'complete' second life and last as an average new product) and the decay in performance is negligible (i.e. $\varphi \approx 1$), this reuse situation (2) converges with the previous situation (1).

Reuse situation (3): the first use of product (A) lasts for the 'expected average lifetime' of the product group (e.g. the product is discarded due to normal wear during the lifetime)

Assumptions:

$a \approx$ T the first use of product (A) will last about the average product life 'T'.

In this situation the previous formula remains in its most generic form:

$$\Delta_{reuse} = \left[\frac{P}{T} + \frac{E}{T} + (u_B - \varphi \cdot u_A)\right] \cdot x - R_A^*$$

In particular, as product (A) is assumed to have a complete first use, it is not straightforward to assume that the energy efficiency of product (A) is the same of that of product (B), or that the product will not suffer a performance loss, especially if assuming a long second life (e.g. x ≈ a). The latter case could occur because of the normal wearing and loss of efficiency of product (A), while the former could be due to the technological evolution of the product group (with more efficient products available on the market as possible substitutes).

A situation of $u_B < u_A$ would be more plausible when the product group has short technological cycles (as for some electronic devices) compared to the average lifetime of the products.

The potential environmental benefits of the reuse of the product in this situation mainly related to the difference in the energy efficiency of the two products[57]. If we express the energy consumption of product (B) as a function of the consumption of product (A), as $u_B = \delta \cdot u_A$, with $0 < \delta \leq 1$ and $x \neq 0$, the previous formula becomes:

$$\Delta_{reuse} = \left[\frac{P}{T} + \frac{E}{T} + (\delta - \varphi) \cdot u_A\right] \cdot x - R_A^*$$

It results that there are some environmental benefits (i.e. $\Delta_{reuse} > 0$) if:

$$(\delta - \varphi) > \frac{1}{u_A} \cdot \left[\frac{R_A^*}{x} - \frac{P+E}{T}\right]$$

$$\varphi < \delta + \frac{1}{u_A} \cdot \left[\frac{P+E}{T} - \frac{R_A^*}{x}\right]$$

In this situation the assessment of the environmental benefits for the reused product is not straightforward, as it depends on a series of factors: first of all the potential performance loss of product (A) and the efficiency of the potentially substituting product (B).

Also in situation (3), the environmental benefits of reuse, when occurring, are higher if $R_A^* \to 0$ (i.e. when the impacts of refurbishment are small) and if $\mathrm{x} \to \mathrm{T}$ (i.e. when the duration of the second life of the product is comparable to the average lifetime of a new product).

2.7.3. Environmental assessment of multiple reuses of the product

A more general assessment method should include potential multiple reuses of a product (Figure 2.13). In this case, the first use is the same in both the 'standard use' and the 'multiple reuse' scenarios. In the 'standard use' scenario, it is assumed that product (A) will be substituted by a newer product (B), and successively by a newer product (B) every time the product reaches its average lifetime.

In the 'multiple reuse' scenario, every time the product completes one of its reuses it undergoes the treatments for refurbishment (with the related impacts 'R^*_{Ai}'), and is reused for a variable time 'x_i'.

For 'n' reuses, the reused product will have an overall operating time of $(a + \sum_{i=1}^{n} x_i)$. For simplicity's sake, it is assumed that product (A) and all replacement products (B) of the 'standard use' scenario have the same impacts for production (P) and EoL (E). Analogously, the energy consumption (U_B) of the replacement products is supposed to be constant.

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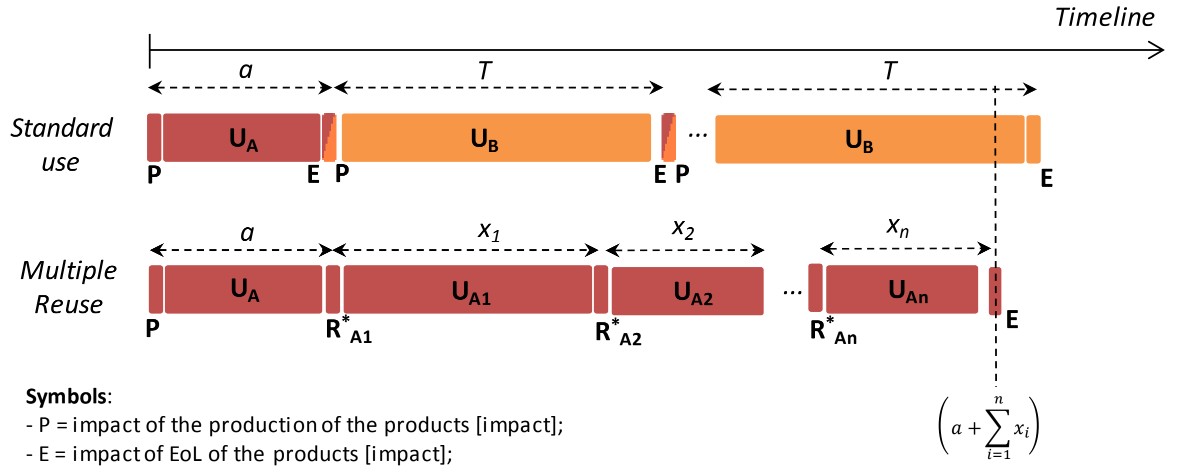
[57] Other differences can occur due, for example, to different use of consumables or different maintenance.

Analogously to the previous assessment method (Section 2.7.1), the efficiency of reused products is estimated as:

$$u_{An} = \varphi_n \cdot u_A \quad : \qquad \varphi_n > 0$$

Also in this analysis, values of ($\varphi_n > 1$) imply higher consumption after reuse (i.e. a performance loss), while values of ($\varphi_n \leq 1$) imply that the performance of the product is either kept constant or improved.



Symbols:
- P = impact of the production of the products [impact];
- E = impact of EoL of the products [impact];
- R^*_{A1} = impact of the first refurbishment [impact];
- R^*_{A2} = impact of the second refurbishment [impact];
- R^*_{An} = impact of the nth refurbishment [impact];
- U_A = impact of using product ‘A’ [impact];
- U_{A1} = impact of using ‘A’, at the first reuse [impact];
- U_{A2} = impact of using ‘A’, at the second reuse [impact];
- U_{An} = impact of using ‘A’, at the nth reuse [impact];
- U_B = impact of the replacing product (B) [impact];
- a = time of the first use of product ‘A’ [year];
- x_n = time of the nth reuse [year];
- T = average lifetime of replacing products [year].

Figure 2.13. Scenarios for the assessment of multiple reuses of a product

Provided parameter ‘m’, calculated as the smallest integer greater than or equal to the ratio between the overall operational time of the reused product and the average lifetime of replacement products, as follows:

$$m \in \mathbb{N} : m = \left\lceil \frac{\sum_{i=1}^{n} x_i}{T} \right\rceil$$

the environmental impact of the two scenarios for the overall time frame can be calculated as follows.

Impacts of the ‘standard use’ scenario:

$$I_{st\_use} = P + U_A + E + (P + E) \cdot m + u_B \cdot \sum_{i=1}^{n} x_i$$

Impacts of the ‘multiple reuse’ scenario:

$$I_{multiple\ reuse} = P + U_A + E + \sum_{i=1}^{n} R^*_{Ai} \quad + u_A \cdot \sum_{i=1}^{n} (\varphi_i \cdot x_i)$$

The difference between the impacts of the two scenarios becomes:

$$\Delta_{reuse} = (P+E) \cdot \frac{\sum_{i=1}^{n} x_i}{T} + \sum_{i=1}^{n} (u_B - \varphi_i \cdot u_A) \cdot x_i - \sum_{i=1}^{n} R_{Ai}^{*}$$

In the case of a single reuse, this formula converges to previous formulas of Section 2.7.1.

It is important to underline how the parameters of this formula are subject to a high degree of variability, in particular due to the assumptions about the number of reuses, the performance loss after each refurbishment and the impacts of each refurbishment. Additional uncertainty could affect the 'standard use' scenario, when the energy efficiency and the operation time of replacement products is not supposed to be constant. Furthermore, the replacement of products in the 'standard use' scenario could be affected by performance loss or failures. For these reasons the analysis of potential multiple reuses will be not considered for the present case-study analysis. This could be part of future methodological developments.

2.8. Environmental assessment of the reuse of products

The formulas in Section 2.7.1 have been applied to the WM and DW case studies of Section 1 to assess the potential benefits/burdens related to the reuse of these products. The environmental assessments are described in the following sections.

2.9. Environmental assessment of the reuse of a WM

2.9.1. Assumptions for the calculations

As general assumption for the modelling, it was assumed that both the case-study WM product and the potential replacement product consume the same amount of water and detergents in all the considered scenarios. The impacts per unit of time ('u_A' and 'u_B') of the previous formulas refer, therefore, only to the impact on the consumption of electricity.

The characteristics and life cycle impacts of the WM are those described in Section 1.3. Concerning the refurbishing operations, based on observations at the reuse centres, the following is assumed.

- The WM, after its first use, is collected and delivered to the reuse centre and, afterwards, the refurbished product is delivered to users. Overall the transport amounts to 200 km with a light truck.
- During refurbishment the WM is subjected to the procedures described in Section 2.4. In particular it is subjected to preliminary tests to identify potential failures and to assess the reuse potential of the machine. WM which are too damaged or that need too burdensome or costly intervention are discarded.
- During refurbishment, repairs generally occur. Impacts due to on-site repairs (e.g. cleaning, soldering, removing obstructions, sealing, etc.) have been considered negligible. However, when necessary, some components can be replaced and spare parts are used. Since a detail of the different spare parts used for each reuse situation was not available, it was assumed to refer to average statistics about repair(Chapter 3). The percentages of the main replacement of components are: door seal (6.5 % of cases), drain pump (6.4 %), heater (2.2 %), PCB (1.3 %) and circulation pump (1.3 %). Moreover, components harvested from previous machines are reused in the following percentages: door seal (1.2 % of cases), drain pump (3.5 %), heater (9 %), PCB (15.4 %) and

circulation pump (33.3 %). When reused components are utilised for refurbishment their impact has been considered to be null. The percentages of replacement of new components are detailed in Table 2.6.

- The WM is then further tested to check the functionalities of the products after refurbishment, and it is finally washed and cleaned. Packaging is not considered.

Table 2.6 summarises the main assumptions used for the calculation.

Table 2.6. Summary of the assumptions for the calculation of the benefits/burdens of the reuse of the WM case study

Assumption	**Value**
Case-study product	Washing machine (7 kg)
Bill of material	(as in Table 1.2)
Average lifetime	12.5 (years)
Energy consumption (in real-life conditions)	147.8 (kWh/year)
Life cycle impacts	(as described in Section 1.3.4)
Impacts of refurbishing	Overall transport, to and from the reuse centre: 200 km, with a light truck. Testing (pre and post refurbishment), including the running of washing tests: electricity 4.02 kWh; water 140.7 litres. Use of water for washing and cleaning operations: 50 litres of water; 100 g detergent (generic). Use of new spare parts: door seal (6.4 % of cases), drain pump (6.2 %), heater (2 %), PCB (1.1 %), circulation pump (0.1 %).
Length of second life	12.5 years (for reuse situation 1 — product lasting for a relatively short time). 4-10 years (for reuse situation 2 — product with an 'intermediate duration' below the average lifetime and reuse situation 3 — product lasting for the expected average lifetime).
Changes in the performance of the refurbished product	$\varphi \in [95\% ; 105\%]$
Efficiency of the replacement product	$\delta \in [70\% ; 100\%]$

2.9.2. Environmental assessment of WM reuse

The environmental assessment of the reuse of WM has been carried out with the GaBi software for the three reuse situations discussed above: 'product failing after a relatively short time', 'product having an intermediate duration (below average the lifetime)' and 'product lasting for the expected average lifetime'.

An average scenario for refurbishment was considered for the assessment of the related impacts (R*), as specific information for different situations was not available. The average scenario is characterised by operations such as transport, checking, testing and cleaning of successfully refurbished products, which are activities that are always performed, no matter the machine and the type of failures encountered. It is recognised that some differences could arise for the repair activities and the spare parts substituted in the three different reuse situations. However, this detailed information is currently lacking[58]. The assumptions described in Section 2.9.1 are therefore based on the repair statistics for products of different ages, and can be considered representative of an average refurbishment of a WM.

2.9.3. Assessment of the reuse of a WM failing after a relatively short time: situation 1

The environmental assessment of the reuse of a WM failing after a relatively short time (situation 1) is shown in Table 2.7. Benefits are estimated for all the impact categories. These benefits relate to the production of materials and components that has been avoided due to the reuse of the product. Benefits are accounted for all impact categories. In particular they are relevant (> 10 %) for the large majority of impact categories, including climate change — GWP (16 %), acidification (47 %) and abiotic depletion — fossil (14.7 %). The benefits are very high (> 50 %) for impact categories such as abiotic depletion potential — elements (99 %), freshwater ecotoxicity (91 %), human toxicity — cancer effects (81 %) and human toxicity — non-cancer (78 %). The lowest benefits are accounted for freshwater eutrophication, since this impact is dominated by the use of detergents during use.

Table 2.7. Environmental assessment of the reuse of WM failing after a relatively short time. Length of second life = 12.5 years

Impact category	**Reuse index (Δ^*_{reuse})**
Acidification midpoint (v1.06) (mole of H+ eq.)	47.0 %
Climate change midpoint, excl. biogenic carbon (v1.06) (kg CO_2 equiv.)	16.0 %
Ecotoxicity freshwater midpoint (v1.06) (CTUe)	91.5 %
Eutrophication freshwater midpoint (v1.06) (kg P eq.)	0.2 %
Eutrophication marine midpoint (v1.06) (kg N equiv.)	4.1 %
Eutrophication terrestrial midpoint (v1.06) (mole of N eq.)	40.0 %
Human toxicity midpoint, cancer effects (v1.06) (CTUh)	80.9 %
Human toxicity midpoint, non-cancer effects (v1.06) (CTUh)	78.0 %
Ionising radiation midpoint, human health (v1.06) (kBq U235 eq.)	4.6 %
Ozone depletion midpoint (v1.06) (kg CFC-11 eq.)	7.1 %
Particulate matter/Respiratory inorganics midpoint (v1.06) (kg PM2.5 equiv.)	56.6 %
Photochemical ozone formation midpoint, human health (v1.06) (kg NMVOC)	25.2 %
Resource depletion water, midpoint (v1.06) (m^3 eq.)	2.5 %
Abiotic depletion (ADP fossil) (MJ)	14.7 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	98.7 %

2.9.4. Assessment of the reuse of a WM having an intermediate duration: situation 2

The results of the environmental assessment of the reuse of a WM having an intermediate duration (below the average expected lifetime, situation 2) are illustrated in Figure 2.14. For this assessment a new parameter (φ) has been introduced to account for the changes in the energy performance of the product after reuse.

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[58] This aspect could be further investigated in future developments of the method and case-studies.

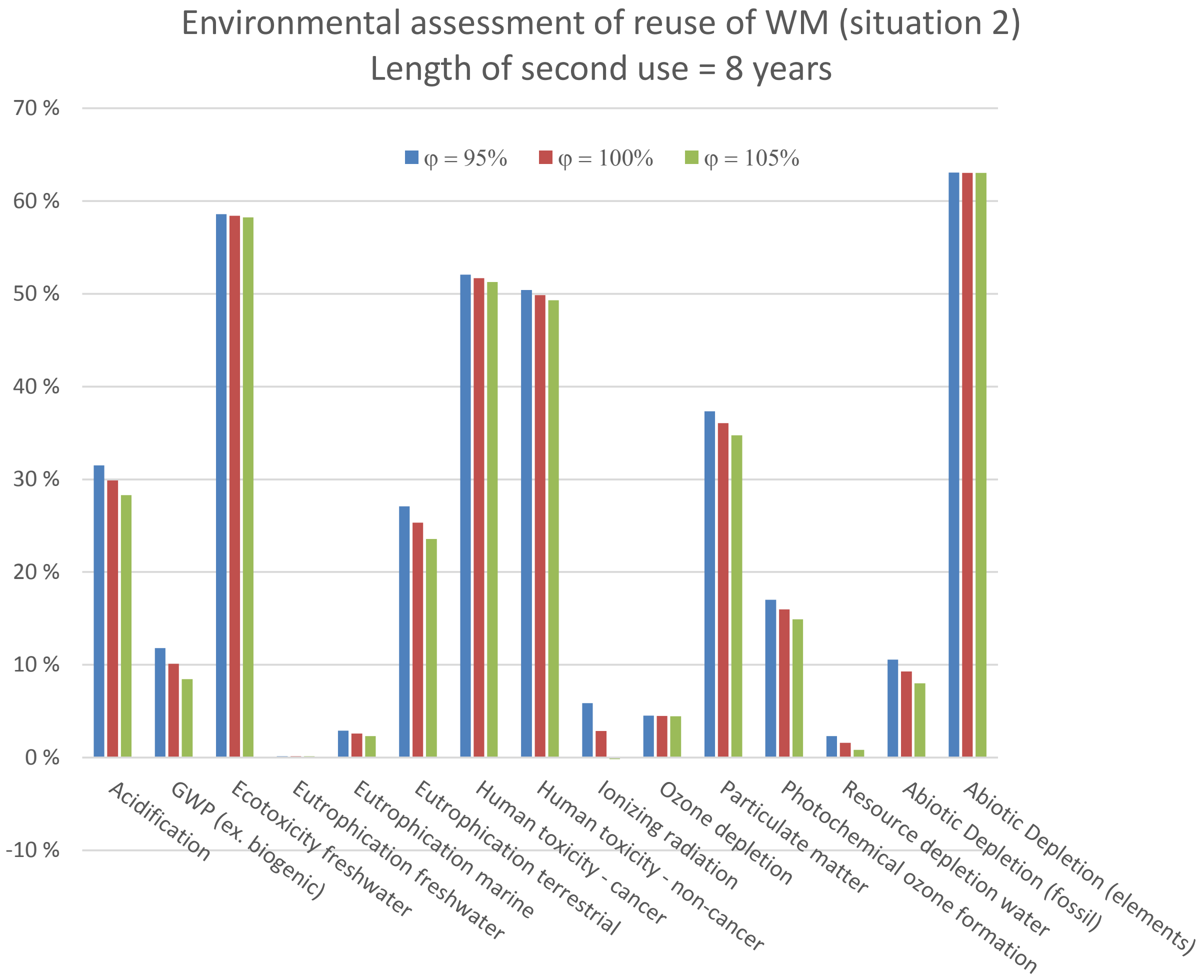

Figure 2.14. Environmental assessment of reuse of WM (situation 2)

Also in this situation, environmental benefits are estimated concerning almost all the impact categories, with the only exception being minor additional impacts for ionising radiation in one scenario[59] and null benefits for freshwater eutrophication. As an example, Figure 2.14 refers to the product's lifetime as being 8 years. It is observed that for the GWP, for example, the benefits are 8 %, 10 % or 12 % depending on whether the energy consumption of the product after refurbishment is increased by 5 % ($\varphi = 105\ \%$; downgrading), maintained ($\varphi = 100\ \%$) or decreased by 5 % ($\varphi = 95\ \%$; upgrading) respectively. Also in this situation high benefits (> 40 %) are estimated for various impacts such as abiotic depletion potential — elements, freshwater ecotoxicity and human toxicity impacts.

Results for different assumptions on the lifetime of the refurbished product are illustrated in Annex B. It is observed that the benefits are larger when the length of the second use increases. This is also the reason for having lower benefits compared to situation 1, due to the assumption of a shorter length of the second reuse.

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[59] The negative value of the ionizing radiation in the scenario of 'Situation 2' is related to the additional impact of energy consumption when the energy performance of the DW are supposed to be downgraded.

2.10. Assessment of the reuse of a WM lasting for the expected average lifetime: situation 3

In this third situation it is assumed that the WM is reused after a first use lasting for the overall average product lifetime. The product, after being discarded by the user, is collected and subjected to the refurbishment treatments described in Section 2.4.

Also in this situation, different scenarios are considered depending on whether the performance of the product after the refurbishment is downgraded ($\varphi = 105\%$), maintained ($\varphi = 100\ \%$) or upgraded ($\varphi = 95\ \%$).

Compared to situation 2, this new situation also assumes that the potential replacement product (B) of Section 2.7.2 will have a different energy efficiency compared to the refurbished product. The main reason for this assumption is that, after the years of the first use of the new product, there are likely to be products on the market with improved efficiency. This variation in the efficiency is represented by the factor 'δ' introduced in the formulas. In the different scenarios it is assumed that $\delta \epsilon [75\ \%; 100\ \%]$.

As discussed in Section 2.7.2, the formula for the assessment of reuse situation 3 can be expressed as function of the difference $(\delta - \varphi)$. The assumed values of $(\delta - \varphi)$ are illustrated in Table 2.8.

Table 2.8. Values of $(\delta – \varphi)$ assumed for the assessment of reuse situation 3

	φ (performance after refurbishment)		
	upgraded	*constant*	*downgraded*
	95 %	100 %	105 %
δ	(δ - φ)		
100 %	5 %	0 %	– 5 %
95 %	0 %	– 5 %	– 10 %
90 %	– 5 %	– 10 %	– 15 %
85 %	– 10 %	– 15 %	– 20 %
80 %	– 15 %	– 20 %	– 25 %
75 %	– 20 %	– 25 %	– 30 %
70 %	– 25 %	– 30 %	– 35 %

The results of the assessment of a reused WM in situation 3 are illustrated in Annex B. Table 2.9 illustrates the results for the climate change impact — GWP. Positive values correspond to an environmental benefit, while negative values correspond to an additional impact.

The refurbishment generally implies benefits for values of $|\delta - \varphi| < 30\,\%$. For example, assuming x = 6 years for the lifetime of the reused product, keeping its efficiency constant ($\varphi = 100\%$), and considering the potential replacement product to have a higher efficiency of 10 % ($\delta = 90$ %), this gives a life cycle reduction of about 5 % in the climate change impact. This value increases when the length of the lifetime increases.

Table 2.9. Assessment of the climate change of a refurbished WM (in reuse situation 3)

x **4 years**	**Climate change (excl. bio.) (kg CO_2 eq.)**		
	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	5.7%	4.9%	4.1%
95 %	4.9%	4.1%	3.2%
90 %	4.1%	3.2%	2.4%
85 %	3.2%	2.4%	1.6%
80 %	2.4%	1.6%	0.7%
75 %	1.6%	0.7%	-0.1%
70 %	0.7%	-0.1%	-0.9%
x **6 years**	**Climate change (excl. bio.) (kg CO_2 eq.)**		
	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	8.8%	7.5%	6.3%
95 %	7.5%	6.3%	5.0%
90 %	6.3%	5.0%	3.8%
85 %	5.0%	3.8%	2.5%
80 %	3.8%	2.5%	1.3%
75 %	2.5%	1.3%	0.0%
70 %	1.3%	0.0%	-1.2%
x **8 years**	**Climate change (excl. bio.) (kg CO_2 eq.)**		
	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	11.8%	10.1%	8.5%
95 %	10.1%	8.5%	6.8%
90 %	8.5%	6.8%	5.1%
85 %	6.8%	5.1%	3.5%
80 %	5.1%	3.5%	1.8%
75 %	3.5%	1.8%	0.1%
70 %	1.8%	0.1%	-1.5%
x **10 years**	**Climate change (excl. bio.) (kg CO_2 eq.)**		
	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	14.8%	12.7%	10.7%
95 %	12.7%	10.7%	8.6%
90 %	10.7%	8.6%	6.5%
85 %	8.6%	6.5%	4.4%
80 %	6.5%	4.4%	2.3%
75 %	4.4%	2.3%	0.3%
70 %	2.3%	0.3%	-1.8%

On the other hand, assuming x = 6 years for the lifetime of the reused product, considering a decrease in the performance of the WM by 5 % (i.e. $\varphi = 105\%$), and considering the potential replacement product to have a higher efficiency of 10 % ($\delta = 90$ %), the benefit for the GWP is lower (3.8 %). Alternatively, for the same scenario, with a replacement product having a higher efficiency of 30 % ($\delta = 70$ %), reuse would imply an increased impact of about 1 % of the GWP.

It should be remembered, however, that the climate change impact is largely influenced by the consumption of electricity during the use phase. For several other categories (such as acidification, ecotoxity, terrestrial eutrophication, human toxicity, particulate matter, photochemical ozone formation and abiotic depletion elements) benefits are always accounted for all the considered values of ($\delta - \varphi$) and x. Such benefits can be up to 80 % of the life cycle impacts.

Also concerning the eutrophication potential — freshwater, benefits are accounted for all the scenarios. However, these benefits are negligible compared to the WM life cycle impacts, since this impact category is dominated by the consumption of detergent during the use phase.

The ozone depletion potential assessment was always beneficial, even if with minor benefits. Finally, the ionising radiation and water depletion potential impacts have a trend similar to that of GWP.

2.11. Environmental assessment of the reuse of a DW

2.11.1. Assumptions for the calculations

As a general assumption for the modelling, it was assumed that both the DW case-study product and the potential replacement product consume the same amount of water and detergents in all the considered scenarios. The impacts per unit of time ('u_A' and 'u_B') of the previous formulas refer, therefore, only to the impact for the consumption of electricity.

The characteristics and life cycle impacts of the DW are those described in Section 1.4. Concerning the refurbishing operations, based on observations at the reuse centres, the following is assumed.

- The DW, after its first use, is collected and delivered to the reuse centre and, afterwards, the refurbished product is delivered to users. Overall the transport amounts to 200 km with a light truck;
- During the refurbishment the DW is subjected to the procedures described in Section 2.4. In particular it is subjected to preliminary tests to identify potential failures and to assess the potential of the machine to be reused. DWs which are too damaged or that need too burdensome or costly an intervention are discarded.
- During refurbishment, repairs generally occur. Impacts due to on-site repairs (e.g. cleaning, soldering, removing obstructions, sealing, etc.) have been considered negligible. However, when necessary, some components can be replaced and spare parts are used. Since a detail of the different spare parts used for each reuse situation was not available, it was assumed to refer to average statistics of a repair centre (Chapter 3). The percentages of the main replacement of components are: circulation pump (9.7 % of cases), drain pump (6.8 %), PCB (3 %), heater (2.6 %) and spray arm (1.3 %). Moreover, components harvested from previous machines are reused in the following percentages: circulation pump (14.3 % of cases), drain pump (7.9 %), PCB (6.6 %), heater (11.5 %) and spray arm (11.1 %). When reused components are utilised for refurbishment their impact has been considered to be null. The percentages of replacement of new components are detailed in Table 2.10.
- The DW is then further tested to check the functionalities of the products after refurbishment, and it is finally washed and cleaned. Packaging is not considered.

Table 2.10 summarises main assumptions used for the calculation.

Table 2.10. Summary of the assumptions for the calculation of the benefits/burdens of the reuse of the DW case study

Assumption	**Value**
Case-study product	Dishwasher (13 ps)
Bill of material	(as in Table 1.11)
Average lifetime	12.5 (years)
Energy consumption (in real-life conditions)	292 (kWh/year)
Life cycle impacts	(as described in Section 1.4.4)
Impacts of refurbishing	Overall transport, to and from the reuse centre: 200 km, with a light truck. Testing (pre and post refurbishment), including the running of washing tests: electricity 5 kWh; water 29 litres. Use of water for washing and cleaning operations: 50 litres of water; 100 g detergent (generic). Use of new spare parts: circulation pump (8.3 % of cases), drain pump (6.3 %), PCB (2.8 %), heater (2.3 %), spray arm (1.2 %).
Length of second life	12.5 years (for reuse situation 1 — product lasting for a relatively short time). 4-10 years (for reuse situation 2 — product with an 'intermediate duration' below the average lifetime and reuse situation 3 — product lasting for the expected average lifetime).
Changes in the performance of the refurbished product	$\varphi \in [95\% ; 105\%]$
Efficiency of the replacement product	$\delta \in [70\% ; 100\%]$

2.11.2. Environmental assessment of DW reuse

The environmental assessment of the reuse of DW has been carried out with the GaBi software for the three reuse situations discussed above: 'product failing after a relatively short time', 'product having an intermediate duration (below average the lifetime)' and 'product lasting for the expected average lifetime'.

An average scenario for refurbishment was considered for the assessment of the related impacts (R*), as specific information for different situations was not available. The average scenario is characterised by operations such as transport, checking, testing and cleaning of successfully refurbished products, which are activities that are always performed, no matter the machine and the type of failures encountered. It is recognised that some differences could arise for the repair activities and the spare parts substituted in the three different reuse situations. However, this detailed information is currently lacking[60]. The assumptions described in Section 2.11.1 are therefore based on the repair

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[60] This aspect could be further investigated in future developments of the method and case-studies.

statistics for products of different ages, and can be considered representative of an average refurbishment of a DW.

2.11.3. Assessment of the reuse of a DW failing after a relatively short time: situation 1

The environmental assessment of the reuse of a DW failing after a relatively short time (situation 1) is shown in Table 2.11. Benefits are estimated for all the impact categories. These benefits are related to the production of materials and components that has been avoided due to the reuse of the product. Benefits are accounted for all impact categories. In particular, they are relevant (> 10 %) for the large majority of impact categories, including climate change — GWP (13 %), acidification (31 %) and abiotic depletion — fossil (16 %). The benefits are very high (> 50 %) for impact categories such as abiotic depletion potential — elements (95 %), freshwater ecotoxicity (88 %), human toxicity — cancer effects (77 %) and human toxicity — non-cancer (65 %). Lowest benefits are accounted for freshwater eutrophication, since this impact is dominated by the use of detergents during use.

Table 2.11. Environmental assessment of the reuse of DW failing after a relatively short time. Length of second life = 12.5 years

Impact category	**Reuse index**
Acidification midpoint (v1.06) (mole of H+ eq.)	30.7 %
Climate change midpoint, excl. biogenic carbon (v1.06) (kg CO_2 equiv.)	12.9 %
Ecotoxicity freshwater midpoint (v1.06) (CTUe)	87.8 %
Eutrophication freshwater midpoint (v1.06) (kg P eq.)	0.8 %
Eutrophication marine midpoint (v1.06) (kg N equiv.)	5.6 %
Eutrophication terrestrial midpoint (v1.06) (mole of N eq.)	25.1 %
Human toxicity midpoint, cancer effects (v1.06) (CTUh)	77.0 %
Human toxicity midpoint, non-cancer effects (v1.06) (CTUh)	65.3 %
Ionising radiation midpoint, human health (v1.06) (kBq U235 eq.)	2.3 %
Ozone depletion midpoint (v1.06) (kg CFC-11 eq.)	7.9 %
Particulate matter/Respiratory inorganics midpoint (v1.06) (kg PM2.5 equiv.)	39.9 %
Photochemical ozone formation midpoint, human health (v1.06) (kg NMVOC)	20.8 %
Resource depletion water, midpoint (v1.06) (m^3 eq.)	4.2 %
Abiotic depletion (ADP fossil) (MJ)	16.3 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	95.5 %

2.11.4. Assessment of the reuse of a DW having an intermediate duration: situation 2

The results of the environmental assessment of the reuse of a DW having an intermediate duration (below the average expected lifetime, situation 2) are illustrated in Figure 2.15. For this assessment a new parameter (φ) has been introduced to account for the changes of the energy performance of the product after reuse.

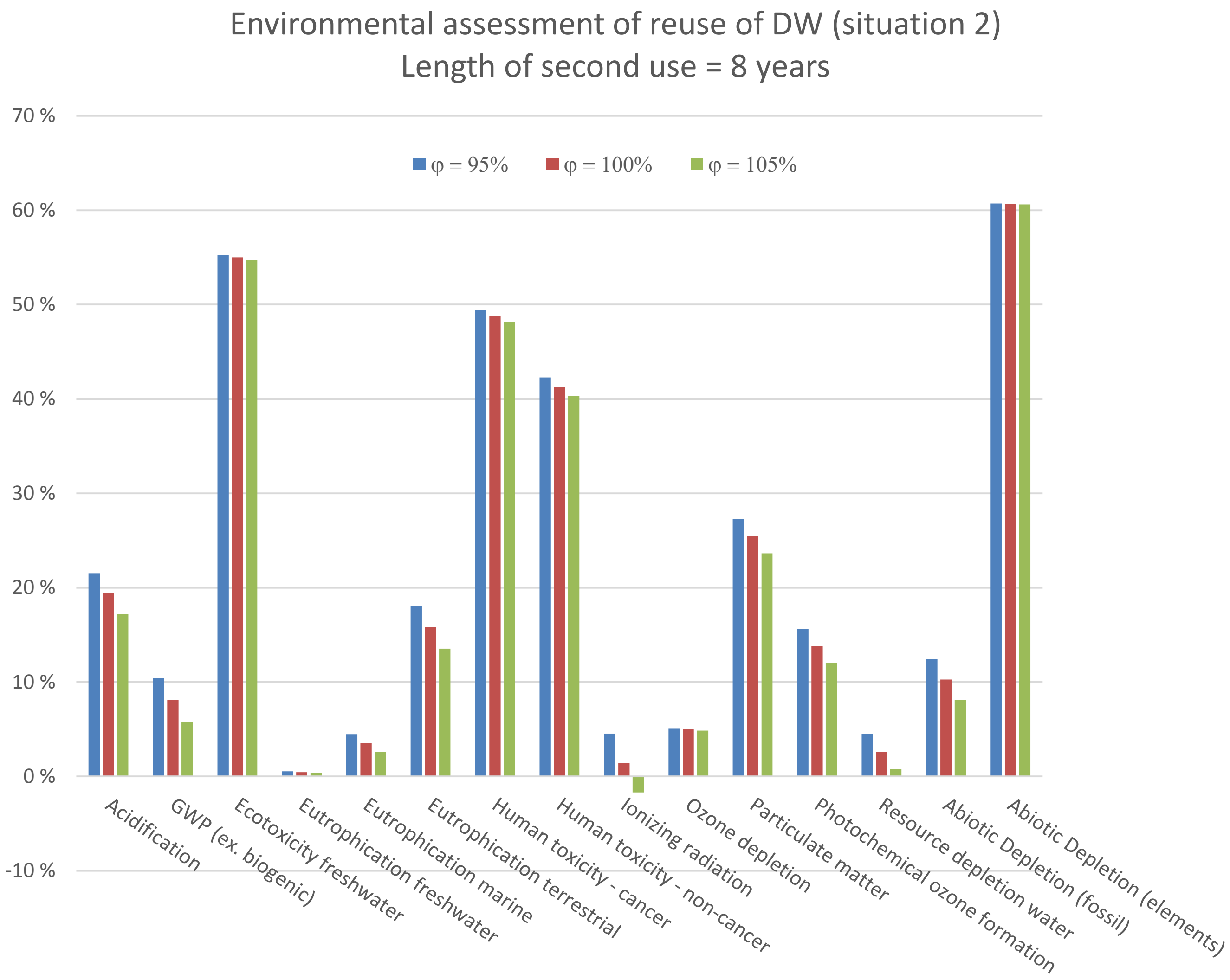

Figure 2.15. Environmental assessment of reuse of DW (situation 2)

Also in this situation, environmental benefits are estimated concerning almost all the impact categories, with the only exception of minor additional impacts for ionising radiation in one scenario[61]. As an example, Figure 2.15 refers to the product's lifetime as being 8 years. It is observed that for the GWP, for example, the benefits are 6 %, 9 % or 12 % depending on whether the energy consumption of the product after refurbishment is increased by 5 % ($\varphi = 105\%$; downgrading), maintained ($\varphi = 100\%$) or decreased by 5 % ($\varphi = 95\%$; upgrading) respectively. Also in this situation high benefits (> 40 %) are estimated for various impacts such as abiotic depletion potential — elements, freshwater ecotoxicity and human toxicity impacts.

Results for different assumptions on the lifetime of the refurbished product are illustrated in Annex B. It is observed that benefits are larger when the length of the second use increases. This is also the reason for having lower benefits compared to the situation 1, due to the assumption of a shorter length of the second reuse.

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[61] The negative value of the ionizing radiation in the scenario of 'Situation 2' is related to the additional impact of energy consumption when the energy performance of the DW are supposed to be downgraded.

2.11.5. Assessment of the reuse of a DW lasting for the expected average lifetime: situation 3

In this third situation it is assumed that the DW is reused after a first use lasting for the overall average product lifetime. The product, after being discarded by the user, is collected and subjected to the refurbishment treatments described in Section 2.4.

Also in this situation, different scenarios are considered depending on whether the performance of the product after the refurbishment is downgraded ($\varphi = 105\%$), maintained ($\varphi = 100\%$) or upgraded ($\varphi = 95\%$).

Compared to situation 2, this new situation also assumes that the potential replacement product (B) of Section 2.7.2 will have a different energy efficiency compared to the refurbished product. The main reason for this assumption is that, after the years of the first use of the new product, there are likely to be products on the market with improved efficiency. This variation in the efficiency is represented by the factor 'δ' introduced in the formulas. In the different scenarios it is assumed that $\delta \epsilon [75\ \%; 100\ \%]$.

As discussed in Section 2.7.2, the formula for the assessment of reuse situation 3 can be expressed as function of the difference ($\delta - \varphi$). The assumed values of ($\delta - \varphi$) are those already used for the WM case study in Table 2.8. The results of the assessment of a reused DW in situation 3 are illustrated in Annex B.

Table 2.12 illustrates the results for the climate change impact. Positive values correspond to an environmental benefit, while negative values correspond to an additional impact.

The refurbishment generally implies benefits for values of $|\delta - \varphi| < 15\ \%$. For example, assuming x = 6 years for the lifetime of the reused product, keeping its efficiency constant ($\varphi = 100\%$) and considering the potential replacement product to have a higher efficiency of 10 % ($\delta = 90$ %), this gives a life cycle reduction of 2.5 % in the GWP. This value increases when the length of the lifetime increases.

On the other hand, assuming x = 6 years for the lifetime of the reused product, considering a decrease in the performance of the DW by 5 % (i.e. $\varphi = 105\%$), and considering the potential replacement product having a higher efficiency of 10 % ($\delta = 90$ %), the benefit in the GWP is very low (0.7%). Alternatively, for the same scenario, with a replacement product having a higher efficiency of 20 % ($\delta = 80$ %), reuse would imply an increased impact of 2.8 % for the GWP.

It should be remembered, however, that the climate change impact is largely influenced by the consumption of electricity during the use phase. For several other categories (such as acidification, ecotoxicity, terrestrial eutrophication, human toxicity, particulate matter, photochemical ozone formation and abiotic depletion elements) benefits are always accounted for all the considered values of ($\delta - \varphi$) and x. Such benefits can be up to 70 % of the life cycle impacts.

Also concerning the eutrophication potential — freshwater, benefits are accounted for all the scenarios. However, this benefits are negligible compared to the DW life cycle impacts, since this impact category is dominated by the consumption of detergent during the use phase.

The ozone depletion potential assessment was always beneficial, even if with minor benefits. Finally, the ionising radiation and water depletion potential impacts have a trend similar to that of GWP.

Table 2.12. Assessment of the climate change of a refurbished DW (in reuse situation 3)

x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
4 years	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	5.0%	3.8%	2.7%
95 %	3.8%	2.7%	1.5%
90 %	2.7%	1.5%	0.3%
85 %	1.5%	0.3%	-0.8%
80 %	0.3%	-0.8%	-2.0%
75 %	-0.8%	-2.0%	-3.2%
70 %	-2.0%	-3.2%	-4.3%
x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
6 years	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	7.7%	6.0%	4.2%
95 %	6.0%	4.2%	2.5%
90 %	4.2%	2.5%	0.7%
85 %	2.5%	0.7%	-1.0%
80 %	0.7%	-1.0%	-2.8%
75 %	-1.0%	-2.8%	-4.5%
70 %	-2.8%	-4.5%	-6.3%
x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
8 years	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	10.4%	8.1%	5.8%
95 %	8.1%	5.8%	3.4%
90 %	5.8%	3.4%	1.1%
85 %	3.4%	1.1%	-1.2%
80 %	1.1%	-1.2%	-3.6%
75 %	-1.2%	-3.6%	-5.9%
70 %	-3.6%	-5.9%	-8.2%
x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
10 years	φ		
δ	**95 %**	**100 %**	**105 %**
100 %	13.1%	10.2%	7.3%
95 %	10.2%	7.3%	4.4%
90 %	7.3%	4.4%	1.5%
85 %	4.4%	1.5%	-1.4%
80 %	1.5%	-1.4%	-4.4%
75 %	-1.4%	-4.4%	-7.3%
70 %	-4.4%	-7.3%	-10.2%

It is also interesting to notice that benefits of reuse for DW are generally lower compared to those estimated for WM in similar scenarios (section 2.10). This is due to the assumptions for the use phase of the base case DW (i.e. higher relevance of the energy consumption for various life cycle impact categories). This determines that losses of efficiency during the reuse (or higher efficiency of the replacing device) makes the reuse of a DW less convenient compared to similar scenarios for WM.

2.12. Discussion and final remarks

The chapter analysed the main activities and processes relating to the reuse of energy-using products, with a special focus on WM and DW case studies. In the context of the EU the analysis proved that there are some advanced examples of reuse centres which are able to give a second life to products that would otherwise be sent for recycling. Moreover, such companies put in place procedures to ensure the high quality of refurbished products in terms of costs, efficiency and safety.

Some barriers to the reuse of products have been identified and discussed. This analysis also allowed the identification of aspects (and strategies) that are relevant for the improvement of the product's 'reusability' (meaning the ability of the product to be reused). These aspects include: (1) the design for disassembly of certain crucial components; (2) the availability of spare parts; (3) the provision of information by manufacturers (such as the product's exploded diagram with a clear list of referenced parts; disassembly information, wiring diagrams and connection diagrams; test/diagnosis programs and error codes); and (4) the possibility to re-program product's software.

However, it was observed in some cases that not all the refurbished products were absorbed by the market. One reason for this situation is the request for high quality product, in good status and reliable. However, another reason is also a general lack of information at the consumer level about the reliability of reuse centres, in terms of the trustworthiness of their processes. Additional guarantees provided by the reuse centres for their products can help to overcome the scepticism of some consumers. In order to promote the market for reused products among different types of clients, reuse centres, together with consumer associations, local authorities and NGOs, should promote suitable informative campaigns to let people know how reuse happens and the effective quality of reused products. The adoption of specific labelling schemes (e.g. the PAS 141 label) and of requirement for the preparation for reuse (e.g. those under development according to prEN 50614) could also support the development of the market of reused products.

The chapter then illustrated a method to assess the potential environmental benefits or burdens due to the reuse of products, based on rigorous mathematical modelling. Different reuse situations have been introduced, mainly depending on the age of the product and the potential length of second or multiple reuses.

The method was illustrated in the WM and DW case studies analysed in Chapter 1. The analysis of DW proved that there are high or very high benefits for the large majority of the impacts considered when the reused DW derives from a relatively short first life (reuse situations 1 and 2). In situation 3, when the product was supposed to have a full first life, the benefits of reuse are dependent on factors such as the length of the second life, the potential drop in the product's efficiency and the efficiency of the replacement product. However, in reuse situation 3 also, benefits were accounted for the majority of impact categories and scenarios. Benefits are also accounted for impact categories largely influenced by the use phase, such as abiotic depletion — fossil and climate change, when the energy consumption of the replacement product is up to 85 % of the energy consumption of the reused product, and for water depletion when the energy consumption of the replacement product is up to 90 % of the energy consumption of the reused product. Finally, it is mentioned that some very low benefits are accounted as well for the freshwater eutrophication impact. However these low benefits are related to the assumed inventory data on detergent (see sections 1.3.5 and 1.4.5). The use of phosphorous-free detergents will decrease the eutrophication impacts of the use phase and consequently will results in higher relevance of reuse for this impact categories well. This result could be confirmed when life-cycle inventory data of phosphorous-free detergents will be available.

Results similar to DW have been observed for the WM case study. However, it is highlighted that the reuse of WM generally implies higher environmental benefits for all the impact categories considered. This can be related to the lower energy consumption during the use phase and, therefore, the environmental assessment of reused WM is less influenced by differences in energy efficiency with the new replacement product and by the potential decreases in energy efficiency (downgrading).

Chapter 3

3. Reparability analysis

3.1. Methodology

The repair of products represents a key aspect for the circular economy and resource efficiency, and is recognised to be a relatively low impacting activity. Compared to recycling, which involves the destruction of products and often heavy industrial processes to recover materials, repair allows to derive a higher value from products (Benton et al., 2015; Deloitte, 2016).

Electrical and electronic equipment, in particular, is one of the fastest-growing waste streams in the EU, with some 9 million tonnes generated in 2005, and expected to grow to more than 12 million tonnes by 2020 (European Commission, 2016). Repair, as well as other resource efficiency aspects, may help in reducing the amount of electrical and electronic waste, by extending the service life of products.

As reported by Deloitte (2016), a recent Eurobarometer survey highlighted that about 77 % of citizens in the EU claim a preference in making an effort to repair their products over purchasing new ones and more than 37 % are willing to buy second-hand household appliances (European Commission, 2014). However, certain goods are replaced rather than repaired, for a variety of reasons: technical barriers (functional obsolescence, software updates and short innovation cycles), economic barriers (uncertainties regarding the guarantee of the repair service; small price differences between the repair and the purchase of a new product may make repair and reuse unattractive) and legal barriers (manufacturers and retailers are not always obliged to provide consumers or the repair market with technical instructions, the expected technical lifetime of the product or the availability of spare parts) (Deloitte, 2016). Nevertheless, at the EU level, there is no legal obligation for manufacturers to make spare parts available for any set period of time after product manufacture (WRAP, 2013); information about the availability of spare parts, however, is addressed at the national level, with the example of the French consumption law of 17 March 2014 (see Section 2.3).

Deloitte (2016) has already published a short list of technical barriers for the two product groups analysed in this report, WM and DW. The outcomes are summarised in Sections 3.2 and 3.3. In synergy with the previous studies, we are complementing this information with a detailed breakdown of the failure modes and repair statistics of DW and WM. This chapter does not include environmental or economic assessments but is the result of a statistical analysis conducted by the authors on a database of service and repair records provided by the repair centre Reparatur- und Service-Zentrum R.U.S.Z[62], located in Vienna. R.U.S.Z led to the creation of Repair Network Vienna, a network of some 60 private, profit-oriented repair companies, followed by another three repair networks in Austria[63]. R.U.S.Z is a best practice within the UN Centre for Urban Settlements (Habitat), and has also won many awards, including the Energy Globe Austria Award 2008, the Austrian Climate Protection Award 2009 and the 'Ideas Against Poverty' Innovation Prize 2009. In 2007 R.U.S.Z contributed to developing the ONR 192102 standard, the Austrian label of excellence for durable, repair-friendly designed

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[62] http://www.rusz.at/

[63] http://www.repanet.at

electrical and electronic appliances, which was last updated in 2014 (ONR 192102, 2014).

The main statistics available for each product group are as follows.

- Temporal distribution of device diagnoses (repair service).
- Classification of devices diagnosed with a single failure mode versus devices diagnosed with multiple failure modes.
- Classification of recurrent failure modes, repaired and unrepaired devices.
- Main reasons not to repair a device.
- Focus on principal failure modes and/or most-repaired components.
- Detailed analysis on a data subset of repair services, collected in the first quarter of 2016.

3.2. Repair statistics for washing machines

The technical barriers[64] already highlighted by Deloitte (2016) for this product group are as follows.

- In order to repair washing machines it is sometimes necessary to attach them to a laptop using special diagnosis software. This software, the training and the technical documentation needed to diagnose the failure are sometimes only available to the after-sales service providers of the manufacturers, which makes repairs difficult for other technicians (see Section 2.6.3.4).
- Diagnosing failures in the electronic boards is sometimes problematic, especially if some boards are sealed with resin and can only be accessed and replaced with great difficulty.
- Door hinges that are fused to the washing machine or screwed from the inside of the device are difficult to replace due to low accessibility.
- Repairing the drum spider, seals, bearings and drum casing is sometimes difficult, especially if the bearings are forced into the tub of the drum (see Section 2.6.3.2). In order to replace them, the whole tub or part of it has to be replaced as well, increasing largely the cost of the repair.

The database provided by R.U.S.Z reports a total of 7 244 repair services (initial diagnoses performed by a technician on a device claimed to be malfunctioning by the owner) registered across 2009-2015. Previous studies focused on smaller samples of data, for instance the results of lifetime studies conducted by Stiftung Warentest[65] on washing machines over timeline 2000-2014 were summarised by (Prakash et al., 2016). Tests considered 600 devices in total and almost 196 different models, of which 41 of them encountered problems during the test for a 10-year usage. Components subject to increased vibration load seemed to fail more often than others. Other reports resulted from online consumer surveys or interviews with manufacturers and experts in the repair industry, identifying door seals and hinges, heating elements, inlet and outlet hoses, drum bearings and motors as the parts that are most prone to wear and that are most likely to need replacing (WRAP, 2011).

The database assessed for the current study includes:

- 61 different brands[66];
- 6 672 services in which technicians detected one or more failure modes;
- 488 services with no failure found[67] by technicians;

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[64] Any product design, choice of materials or difficulty in disassembling the components that may hinder repair is categorised as a 'technical barrier'.

[65] https://www.test.de

[66] The 'brand' is the commercial name that helps to distinguish a company from its competitors. It may correspond to the manufacturer's name.

- 84 services in which the failure mode was classified as 'unknown' as it was not identifiable.

In the 7 244 repair services, various actions were carried out depending on the initial diagnosis:

- 5 106 cases were successfully completed with a repair action;
- 489 cases with no failure found were excluded, as no actions were carried out by technicians on the device;
- 1 634 services in which repair actions were not performed by technicians due to economic or technical barriers (repair technically infeasible, too expensive/economically infeasible);
- 15 services were classified as 'partial repair' (in case of partial actions for multiple failure modes detected on the device).

The data are shown in the pie charts in Figure 3.1.

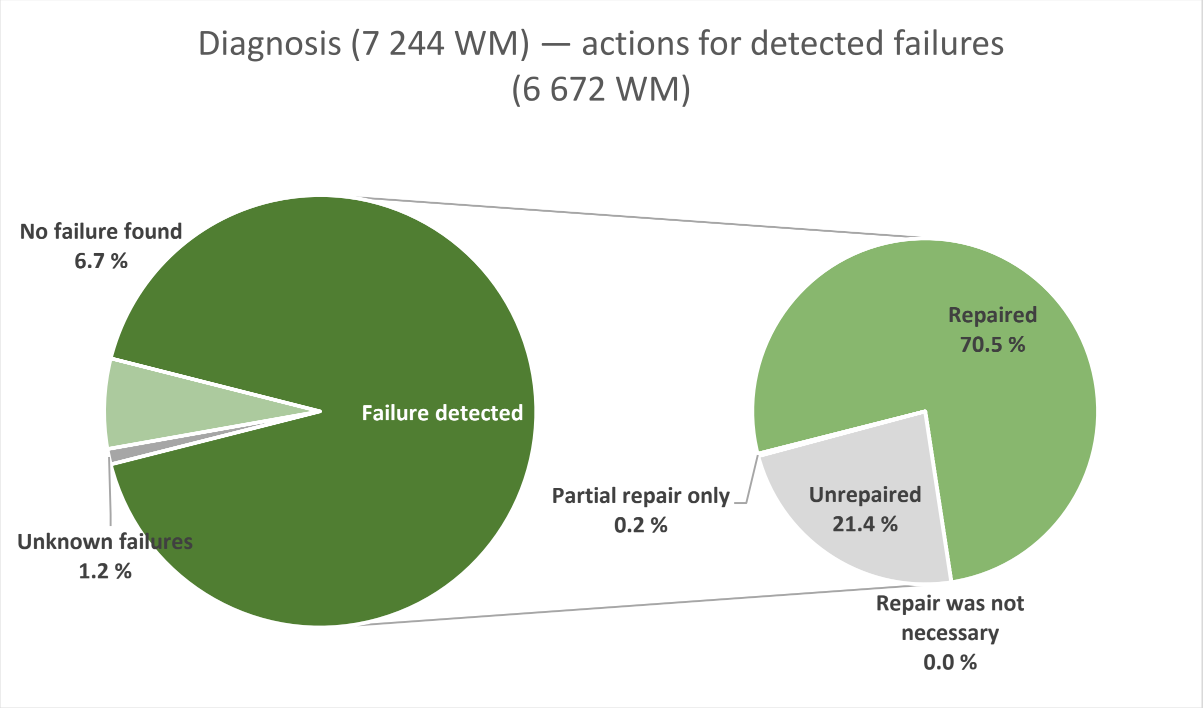

Figure 3.1. Overview of diagnosis for the 7 244 WM and subsequent repair actions if failures were detected (percentages may not total 100 % due to rounding)

3.2.1. Temporal distribution of repair services

Repair services were recorded from 2009 to 2015. On average about 1 000 services are provided for washing machines every year (Figure 3.2).

A subset of repair services for the first quarter of 2016 was further analysed thanks to additional details provided by R.U.S.Z about recent devices at the moment of failure. This additional analysis is discussed in Section 3.2.11.

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[67] 'No failure found' included situations such as: blocked drainage (outside the device/in the wall), water tap closed or defective, power plug off, activated child safety lock, electronics that became wet and dried out in the meantime.

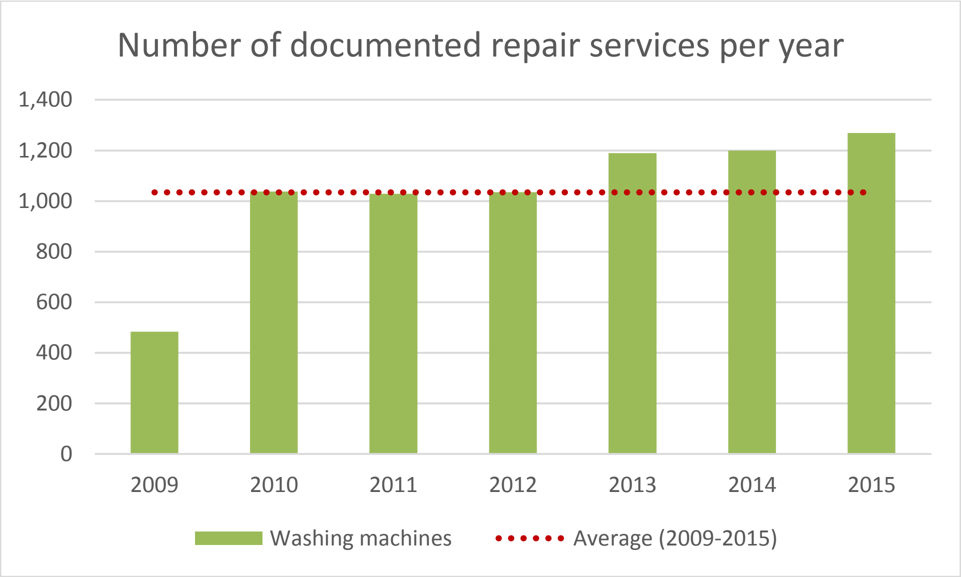

Figure 3.2. Evolution of the documented repair services provided by R.U.S.Z over the 2009-2015 period

3.2.2. Single failure mode vs multiple failure modes

A first classification of datasets was made to divide repair services in which only one failure mode was identified from repair services in which multiple failure modes were detected. In detail:

- single failure mode: one defective component or one failure mode was identified during the diagnosis;
- multiple failure modes: two or more defective components or failure modes were identified during the diagnosis.

Figure 3.3 depicts the breakdown between devices diagnosed with single failure mode or multiple failure modes. Multiple failure modes occurred in almost 30 % of cases. For these datasets it was not possible to identify which failure mode triggered the others, nor whether there was a clear connection between failure modes on the same device.

Devices with multiple failure modes were not repaired in 43 % of cases, while devices with single failure modes were not repaired in only 15 % of cases. This highlights how multiple failure modes are certainly more difficult to handle, depending on the type of failure mode and on the type of repair (economically feasible or infeasible; technically possible or impossible).

Figure 3.4 gives an overview of the different actions on devices with a single or with multiple failure modes, and it is possible to identify these two different trends. Partially repaired devices (identified in the chart with the label ‘partial’) refer to devices with multiple failure modes, for which the repair was not totally successful, i.e. at least one failure mode was not repaired. This is a relatively small subset of data, considered as a group of outliers for the statistical analysis.

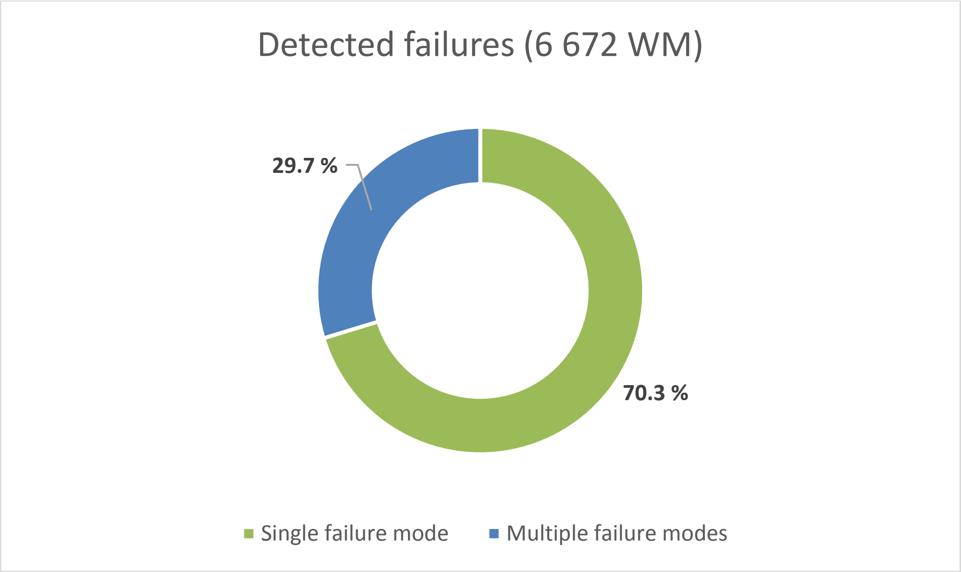

Figure 3.3. Breakdown of repair services in which the device had a single failure mode and multiple failure modes

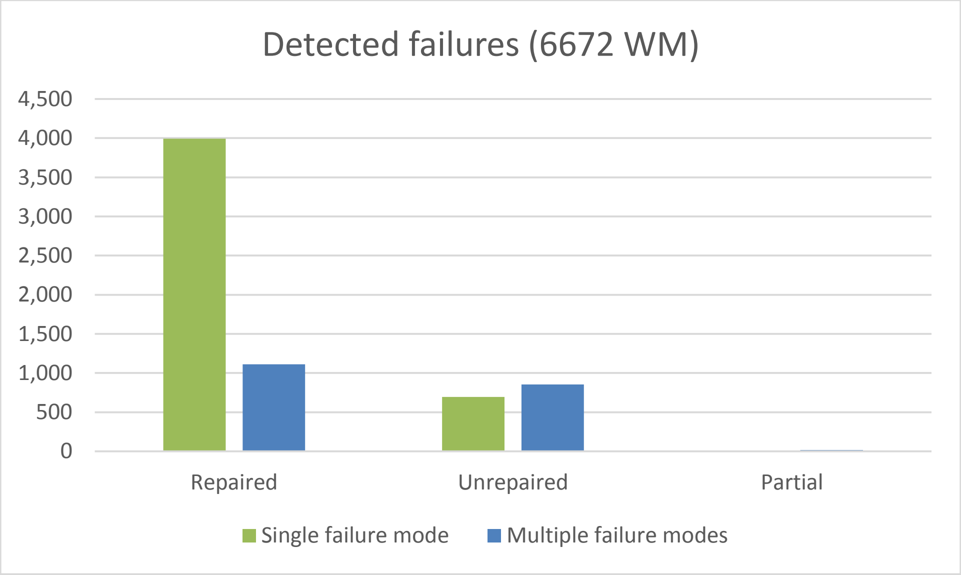

Figure 3.4. Repaired, unrepaired and partially repaired devices, divided by single and multiple failure modes

3.2.3. Identified failure modes

Failure modes were identified by R.U.S.Z and entered into the database of repair services. In order to allow a better overview of results and to identify the main hotspots for the product group, failure modes were categorised and grouped as listed below:

- electronics — control electronics, engine electronics/inverter electronics, relays, programs selectors or control panels, line filters, displays;
- shock absorbers, bearings, ball bearings;
- doors, door handles, hinges, locks and seals;
- carbon brushes;

- circulation pumps and drain pumps;
- foreign objects detected;
- drain hose/outlet hoses, drain systems, inlet hoses;
- mechanical or electronic aquastop or other inlet valves;
- float switches, micro switches, on-off switches, keypad;
- engine, engine condenser and tachogenerator;
- pump filters;
- drive belt/pulley;
- heater and thermostats;
- drum and tub;
- pressure chamber, pressure control, air hoses;
- detergent drawer and detergent hose;
- cables and plugs;
- other (unusual) failure modes.

Group categories were used to limit the number of possible failure modes and to optimise the overview of data. The rationale behind this layout was to group together components with a similar function (e.g. circulation pumps and drain pumps), washing machine parts linked to the functioning of a main device component (e.g. door handles, hinges, locks and seals, all of them key elements of the washing machine door) or components with a complementary function (e.g. shock absorbers and bearings, two machine elements linked to the functioning of the tub, the first aiming at reducing friction between moving parts, the second aiming at absorbing and damping shock impulses).

By combining single and multiple failure modes a total of 9 492 specific failure modes were observed in a sample of 6 672 devices (Figure 3.5). Most recurring failure modes involved the electronics (including control electronics, control panels, program selectors, relays, line filters, etc.), shock absorbers and bearings, doors (including seals, handles, hinges and locks) and carbon brushes. Even though electronics and shock absorbers and bearings were the two most recurring failure modes, they do not represent the most-repaired parts. The highest record of positive repairs relates to doors, with 883 positive repairs, while carbon brushes are ranked second, with 664. Overall, 69 % of the identified failure modes were successfully repaired.

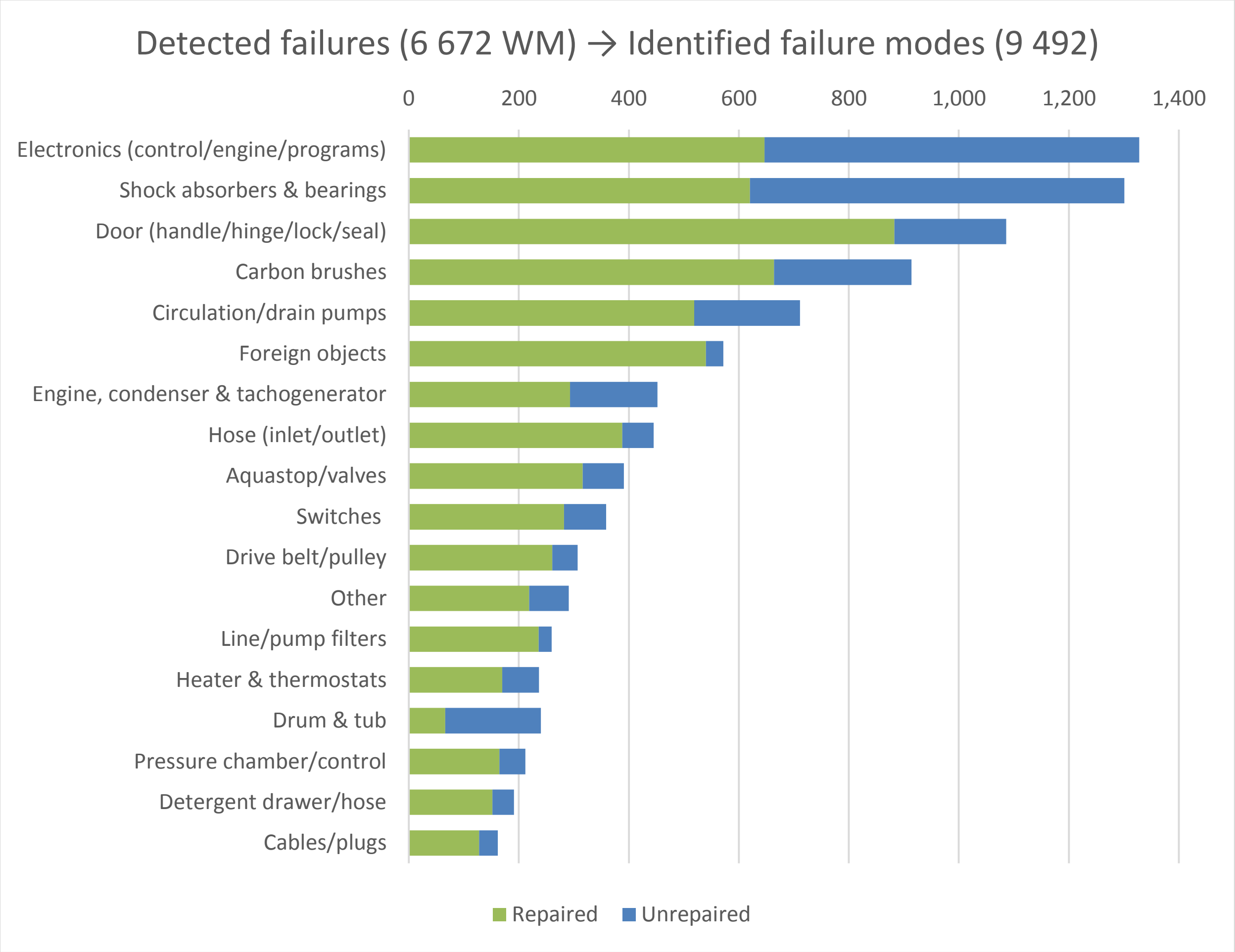

Figure 3.5. 6 672 repair services with detected failures resulted in 9 492 total failure modes — the chart also differentiates between repaired and unrepaired devices

3.2.4. Main reasons not to repair a device

Before addressing specific failure modes and carrying out actions it is important to analyse which drivers lead to the decision not to repair a device. Only a subset of the database was used for this analysis; repair services with single failure modes were considered for this analysis, as records with multiple failure modes could not provide the same level of detail for each category (decisions cannot always be directly related to a specific failure mode). The main reasons not to repair a WM were divided into three categories, as follows.

- Consumer choice: the repair was technically possible but considered too expensive by the customer (considering the overall repair cost, including the cost of the labour and the cost of the spare part(s)).
- Economically non-viable: the repair was technically possible but considered economically infeasible by the technician; economically non-viable repairs were affected by the price of spare parts and/or by the excessive amount of working time required.
- Technically infeasible: the repair was not technically possible. Repairs were impossible for various reasons, mainly because spare parts were not available or because of an ineffective design for disassembly (e.g. fragile plastic clamp connections, sealed bearings to single part plastic tub, bearings and tubs separable only by destructive dismantling). Technically infeasible repairs are connected to the unavailability of spare parts or spare parts no longer being

available and to parts that were built in such a way that they cannot be repaired due to design issues such as clinched, bonded or fused parts. Also the lack of access to software for diagnosis often led to repairs being impossible, as there was no tool to detect the failure, to test the device or, in a few cases, to delete the failure codes.

Figure 3.6 provides an overview of unrepaired devices, with details of the reasons for each main failure mode[68]. In most cases repairs were possible but considered too expensive by the customer (78 % of the repair services considered). In 15 % of cases the repair was classified as technically infeasible, while a non-viable repair was reported in only 7 % of the considered cases.

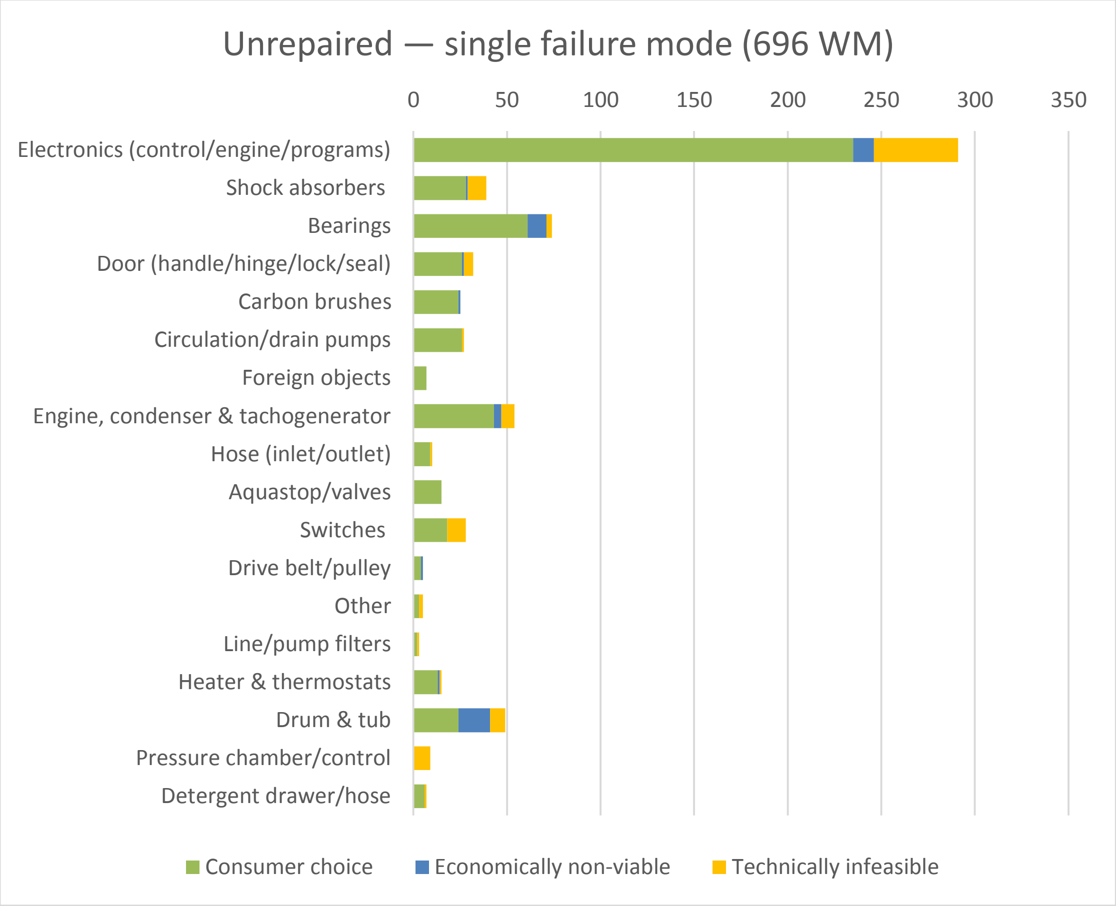

Figure 3.6. Main reasons not to repair a device, categorised by failure mode

3.2.5. Repair services that involved the replacement of a component

Another analysis was carried out to understand which failure modes most often required the replacement of a component. As in the previous case, only a subset of the database was used for this analysis, namely the repair services with single failure modes, since datasets with multiple failure modes could not provide the same level of detail for each category. Overall, 4 690 datasets were considered. In about 58 % of cases the repair involved the replacement of a component, while in 27 % of cases it did not require a

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[68] The failure category 'Shock absorbers and bearings' was split, as the reasons not to repair a device were substantially different.

spare part; the remaining 15 % is the percentage of devices that were not repaired. Looking at the specific failure mode categories it is possible to observe various trends. The failure modes that most often required the replacement of a component were the carbon brushes (98 % of repaired cases), shock absorbers and bearings (98 %), aquastop/valves (93 %), heater and thermostat (89 %) and door and door parts (88 %). On the other hand, the failure modes that did not very often require the replacement of a component were the hose (33 %), the detergent drawer/hose (32 %), filters (27 %) and, of course, the category of foreign objects detected in the device (2 %).

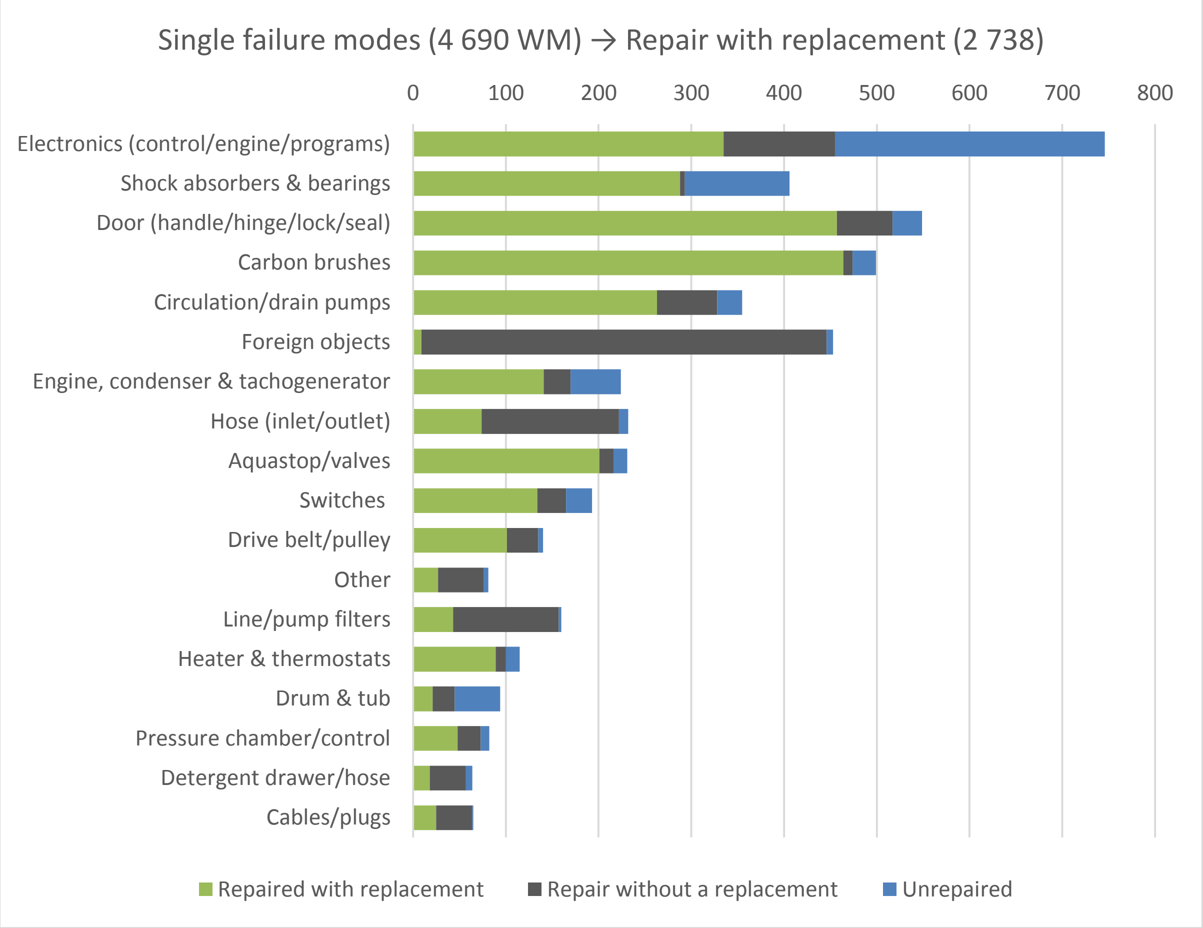


Figure 3.7. Repair services that involved the replacement of a component, divided by category

3.2.6. Failure category 'Door'

The failure category 'door' includes various components of a washing machine door, principally seals, locks, hinges and handles. Failures of seals and locks, in particular, were observed in the majority of the repair services for this category. Technicians also highlighted an increasing tendency in manufacturing doors and hinges so they cannot be repaired, but must be replaced as a whole. The failure mode is distributed equally between single and multiple failure modes; nevertheless, it represents the most-repaired type of failure. Table 3.1 summarises the main outcomes of this failure category, showing the number of failure modes identified, divided into: repaired, unrepaired or partially repaired; single failure mode or multiple failure modes; door seals (focus in Figure 3.8), door locks (focus in Figure 3.9) or other components.

Table 3.1. Breakdown of the failure category related to washing machine doors (number of identified failure modes) — focus on door seals and door locks

Door seals, locks	**Total** **1 090**	**Repaired** **883**	**Unrepaired** **203**	**Partial** **4**
Single failure mode	549	517	32	0
Multiple failure modes	541	366	171	4
Totals	*1 090*	*883*	*203*	*4*
Door seals	637	515	120	2
Door locks	246	196	50	0
Other (hinges, etc.)	207	172	33	2
Totals	*1 090*	*883*	*203*	*4*

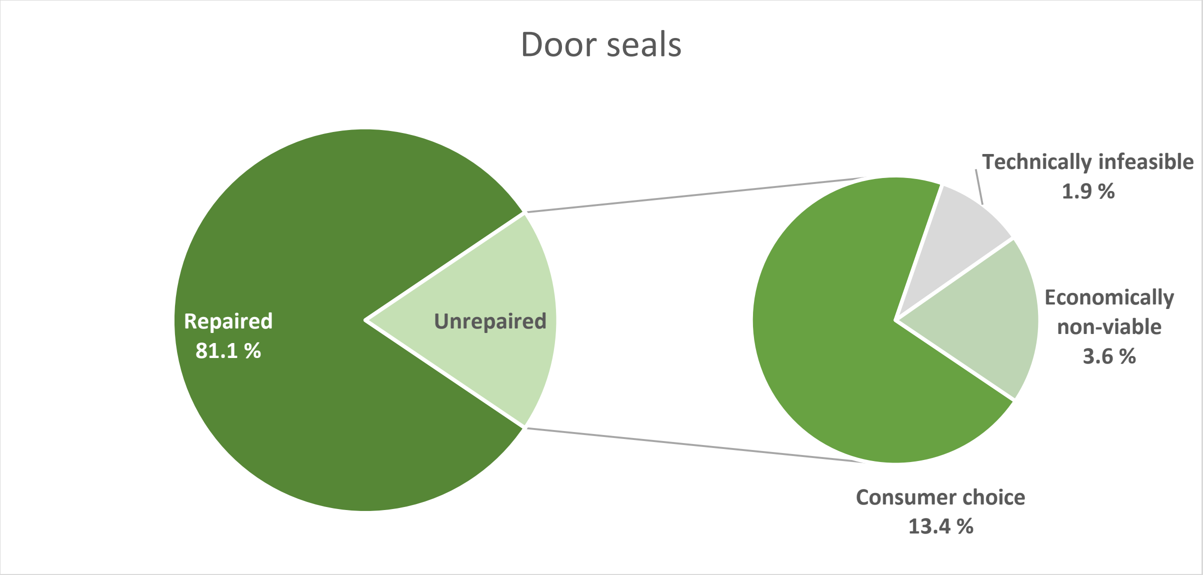


Figure 3.8. Door seals: repaired vs unrepaired

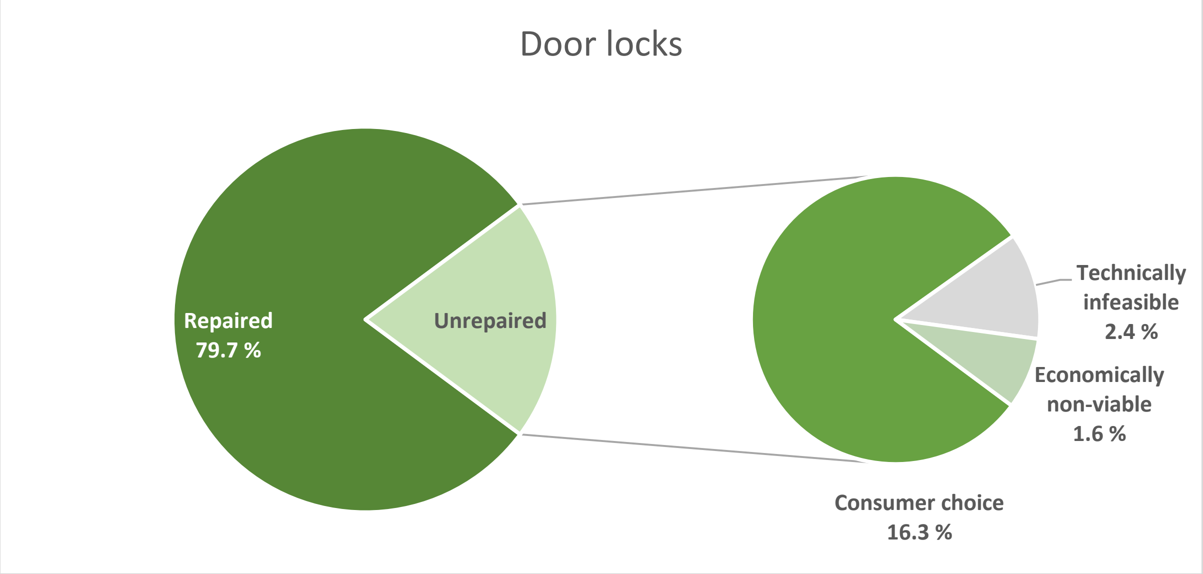


Figure 3.9. Door locks: repaired vs unrepaired

3.2.7. Failure category 'Shock absorbers and bearings'

The failure category focused on bearings and shock absorbers is ranked at the top of the frequent failure modes, excluding electronics. With this failure mode it is very likely to have a case of multiple failure modes (69 % of cases). Table 3.2 provides and overview of the two main failures, highlighting how the majority of bearing-related failures are not repaired because of the high cost (Figure 3.10). On the other hand, shock absorbers are repaired in almost 58 % of cases, but the high cost of repairs is again the main deterrent for unrepaired devices (Figure 3.11).

Table 3.2. Breakdown of the failure category related to washing machine bearings and shock absorbers (number of identified failure modes)

	Total	Repaired	Unrepaired	Partial
Shock absorbers and bearings	**1 308**	**620**	**681**	**7**
Single failure mode	406	293	113	0
Multiple failure modes	902	327	568	7
Totals	*1 308*	*620*	*681*	*7*
Bearings	395	93	301	1
Shock absorbers	903	518	379	6
Other/Not specified	10	9	1	0
Totals	*1 308*	*620*	*681*	*7*

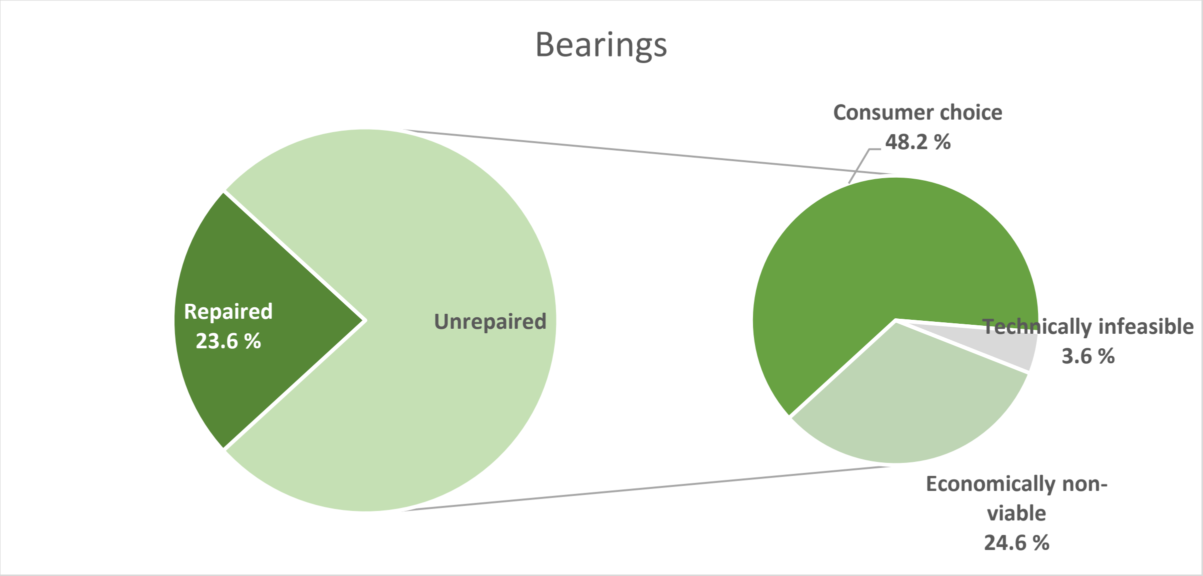


Figure 3.10. Bearings: repaired vs unrepaired

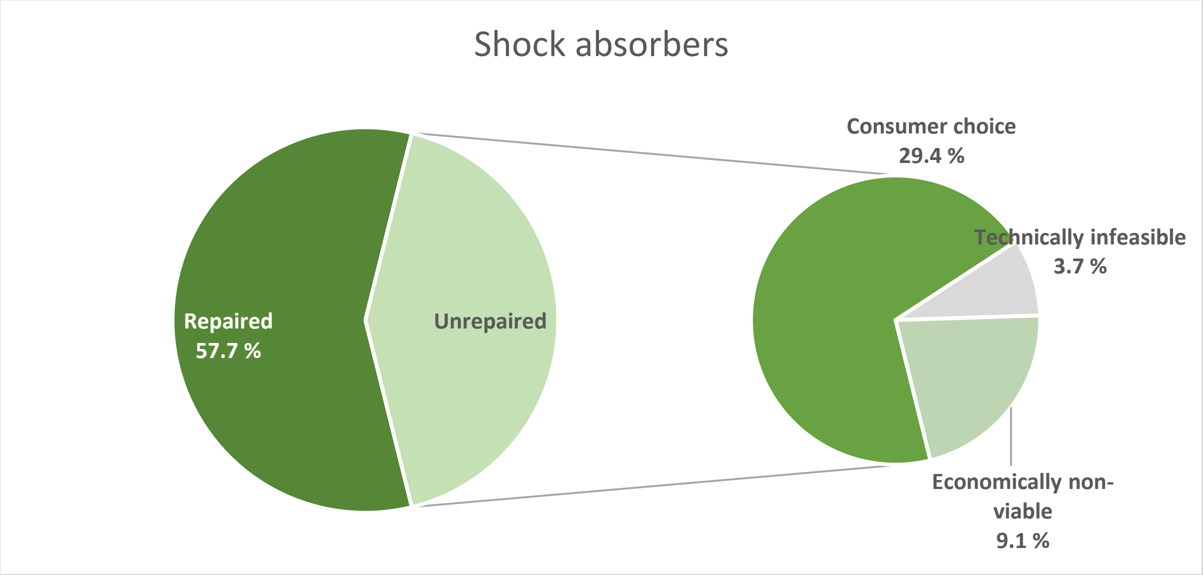


Figure 3.11. Shock absorbers: repaired vs unrepaired

3.2.8. Failure category 'Pumps'

Washing machine pumps represent another frequently failing component. As in the case of 'Doors', the failure mode is equally distributed between single and multiple failure modes (Table 3.3). Drain pumps are repaired in almost 75 % of cases (Figure 3.13). On the other hand circulation pumps are repaired in only 33 % of cases (Figure 3.13). Repair costs again play a key role in decision-making.

Table 3.3. Breakdown of the failure category related to washing machine pumps (number of identified failure modes) — focus on drain and circulation pumps

	Total	**Repaired**	**Unrepaired**	**Partial**
Pumps	**713**	**519**	**193**	**1**
Single failure mode	356	328	28	0
Multiple failure modes	357	191	165	1
Total	*713*	*519*	*193*	*1*
Drain pump	683	508	174	1
Circulation pump	25	8	17	0
Not specified	5	3	2	0
Total	*713*	*519*	*193*	*1*

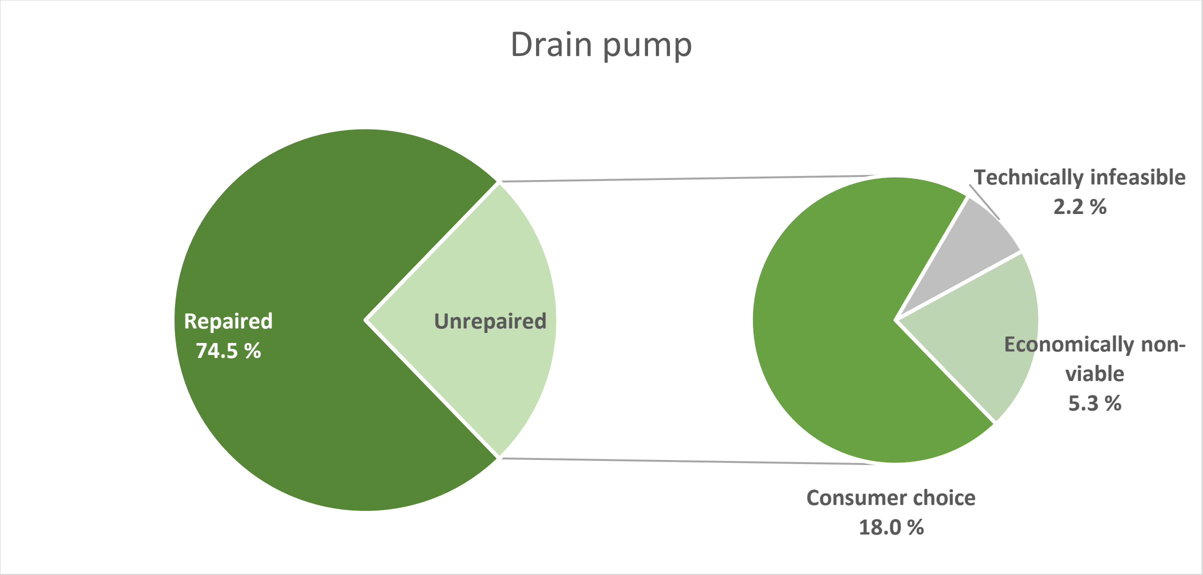


Figure 3.12. Drain pumps: repaired vs unrepaired

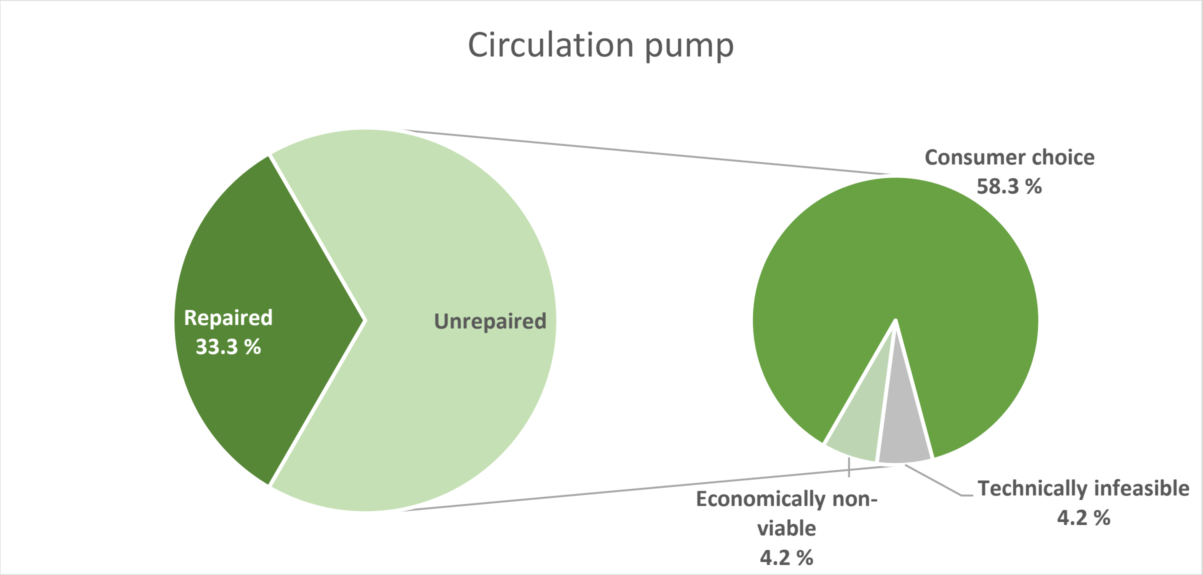


Figure 3.13. Circulation pumps: repaired vs unrepaired

3.2.9. Failure category 'Electronics'

Electronics represented the most frequently failing components for the washing machines analysed. The failure category includes various components, almost exclusively at the hardware level, such as control electronics, control panel, program selectors, relays, line filters, etc. However, in the majority of cases (almost 54 %), a generic label 'Electronics' was recorded by technicians. 'Control electronics' was listed second, with 38 % of cases (Table 3.4); this subgroup includes control electronics, control panels and program selectors. 'Other electronics' includes relays, line filters, fuses, etc. In almost 44 % of cases electronics were involved in multiple failure modes, but, as in the previous cases, it is not clear whether other failure modes caused an electronic failure or vice versa. Repairs in this category were generally difficult: only 41 % of cases for the 'Control electronics' category (in almost 10 % of cases the repair was not technically possible) and 50 % for unspecified 'Electronics' (Figure 3.14 and Figure 3.15).

Table 3.4. Breakdown of the failure category related to washing machine electronics (number of identified failure modes)

Electronics (total)	**Total** **1 328**	**Repaired** **647**	**Unrepaired** **681**	**Partial** **0**
Single failure mode	746	455	291	0
Multiple failure modes	582	192	390	0
Total	*1 328*	*647*	*681*	*0*
Control electronics	509	209	300	0
Electronics (unspecified)	712	357	355	0
Other electronics	107	81	26	0
Total	*1 328*	*647*	*681*	*0*

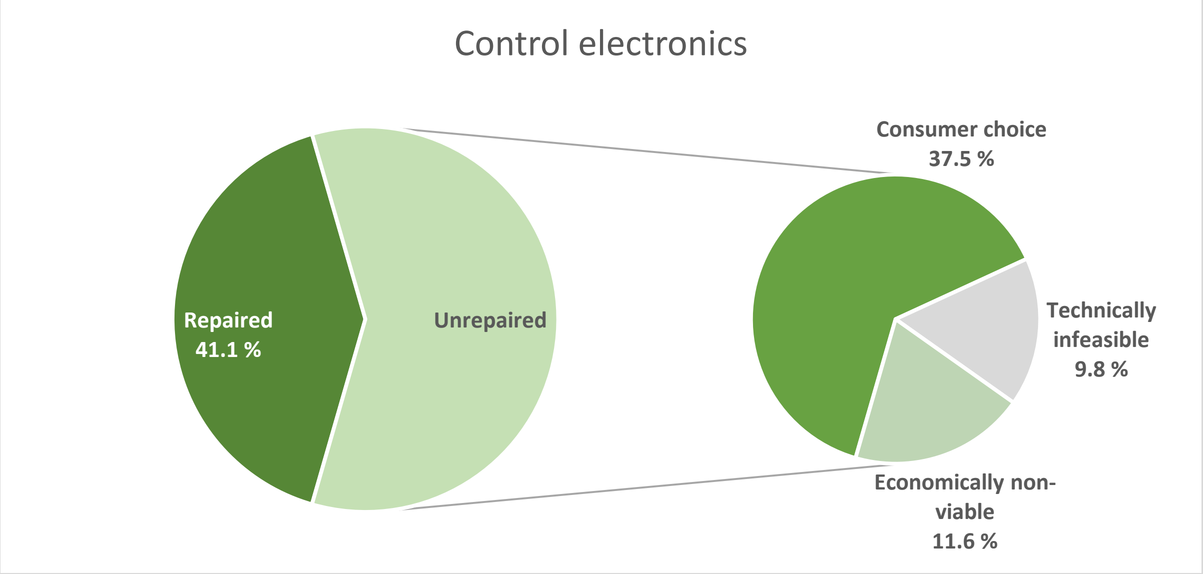


Figure 3.14. Control electronics: repair vs unrepaired

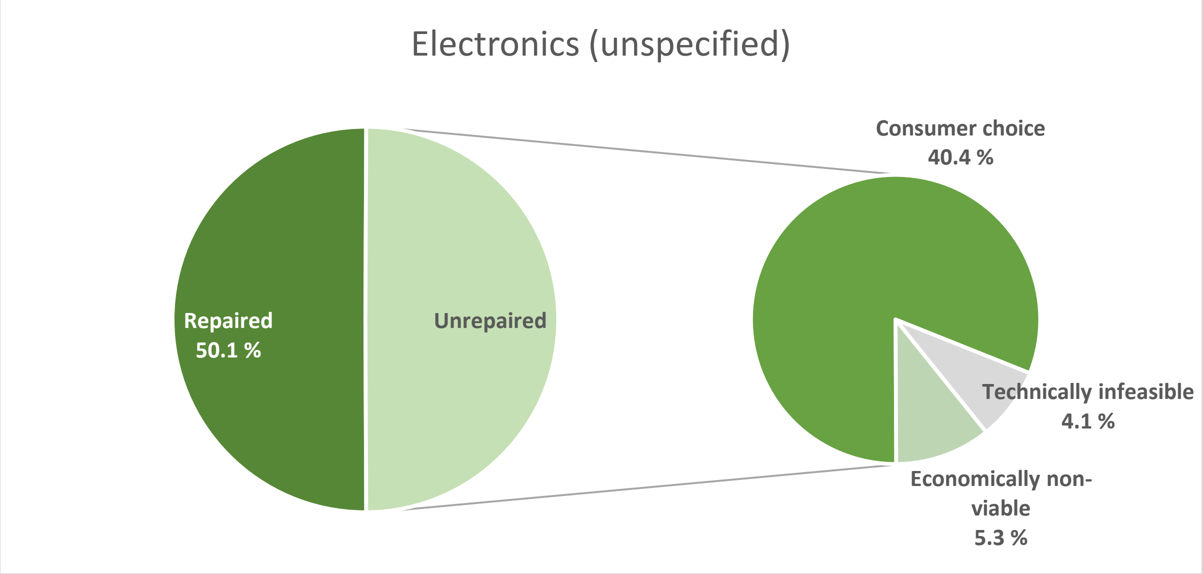


Figure 3.15. Unspecified electronics: repair vs unrepaired

3.2.10. Spare parts: new components or reused components

A repair centre typically collects functioning spare parts from devices at the end of their life, which can be reused for future component replacements on other devices. It was then interesting to analyse the percentages of reused components and new components used for replacements during repairs. Only single failure modes were considered for this analysis, as records with multiple failure modes could not provide the same level of detail for each category. Out of 3 993 cases that had been successfully repaired, 2 721 required the replacement of a defective component: 2 527 records involved the use of a new component, while 194 cases could take advantage of a reused component, i.e. a part extracted from another WM.

In absolute values, reused components were mainly used to replace electronics, door components and engine components; nevertheless, the highest relative percentages of reused components are for the drum and tub, and engine categories, each at about 29 %.

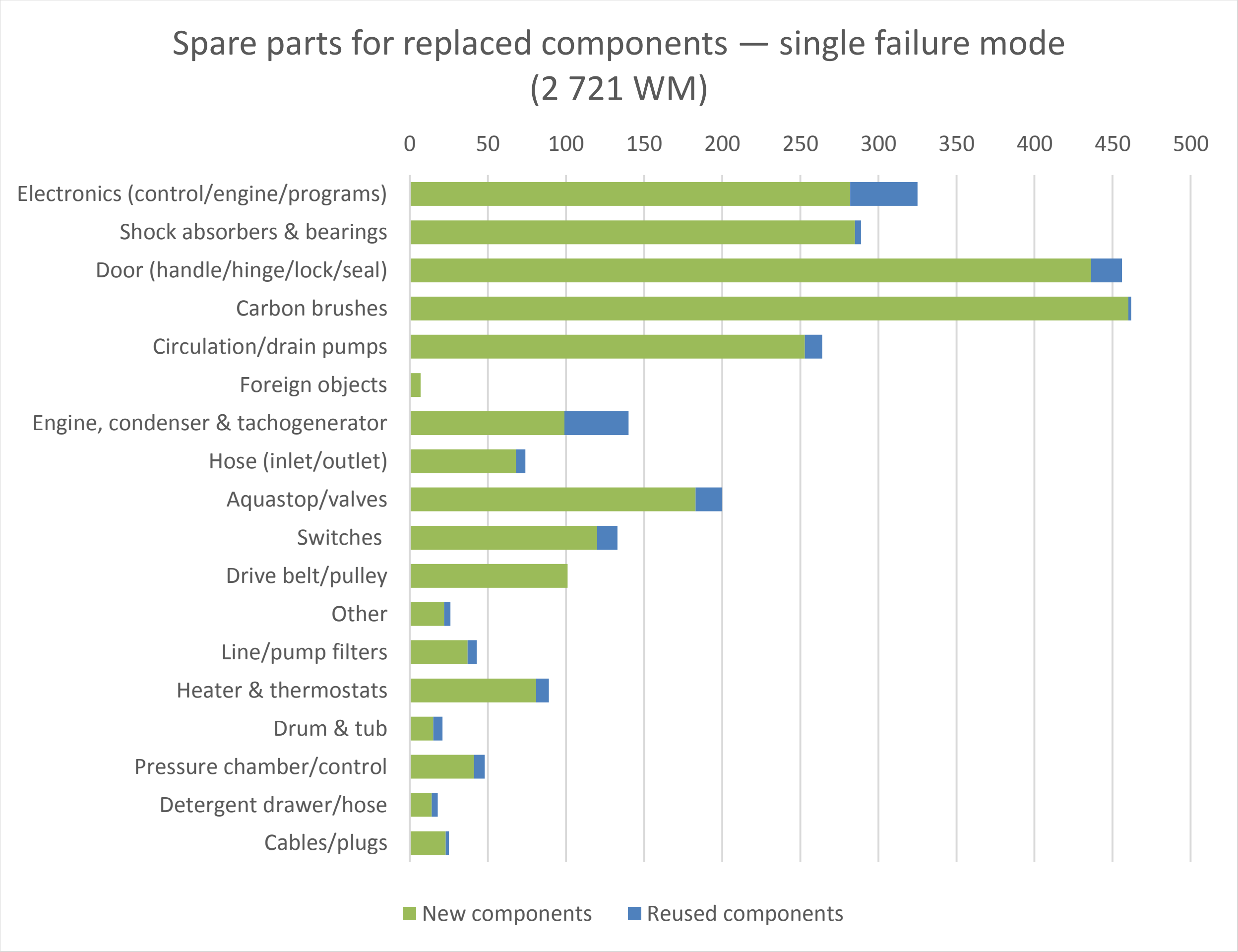


Figure 3.16. New and reused components used as spare parts for replacements

3.2.11. Detailed analysis on the 2016 data subset

As mentioned in Section 3.2.1, an additional analysis was performed on a subset of repair services occurring in the first quarter of 2016 thanks to a more detailed questionnaire used to classify devices at the moment of failure. Additional information included in the questionnaire was:

- the age of the device at the moment of the repair service;
- the average use rate by the user (washing cycles/week);
- the number of previous repair services (if any).

The age of the device at the moment of the repair service was then classified into different groups:

- 0-2 years
- 3-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- 21-25 years
- ≥ 26 years
- not known/did not answer.

The 2016 database is made up of a total of 428 WM. In 255 cases the customer was able to answer the three questions mentioned above. Figure 3.17 gives an overview of the 255 devices classified with the more detailed questionnaire: the majority of them were brought to R.U.S.Z in the 6-10-year and 11-15-year age classes, with an average value of 12.7 years (this value cannot be considered as an estimation of the lifetime of the device). Considering mean values, it emerged that:

- 14.3 years is the average age of devices that had already had at least one previous repair at the moment of the diagnosis;
- 10.2 years is the average age of devices that had never had a previous repair at the moment of the diagnosis;
- 13.2 years is the average age of devices successfully repaired by repair centre operators;
- 12.6 years is the average age of devices not repaired by repair centre operators.

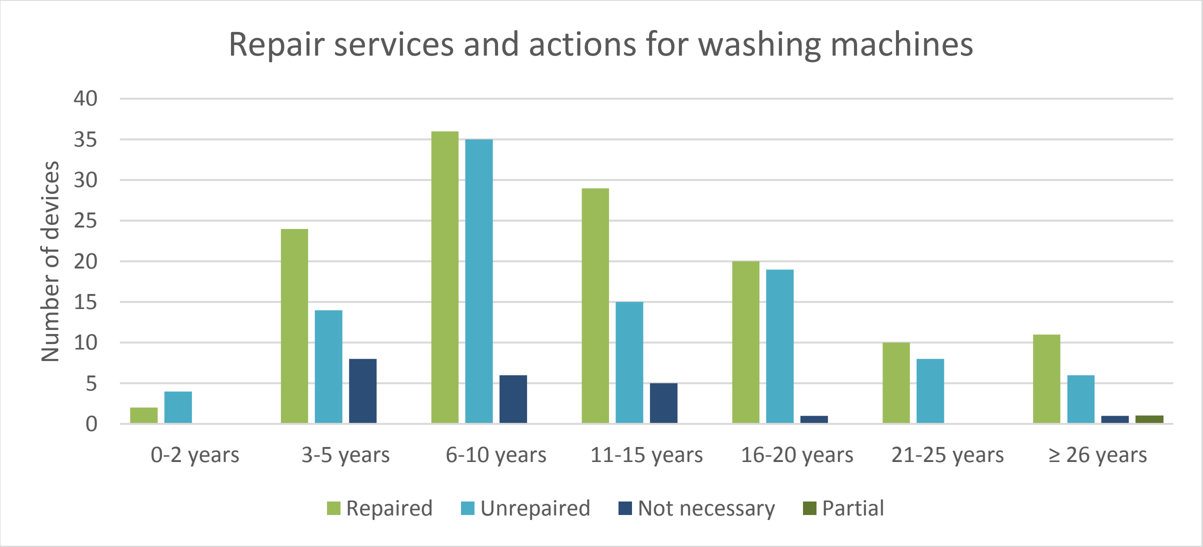
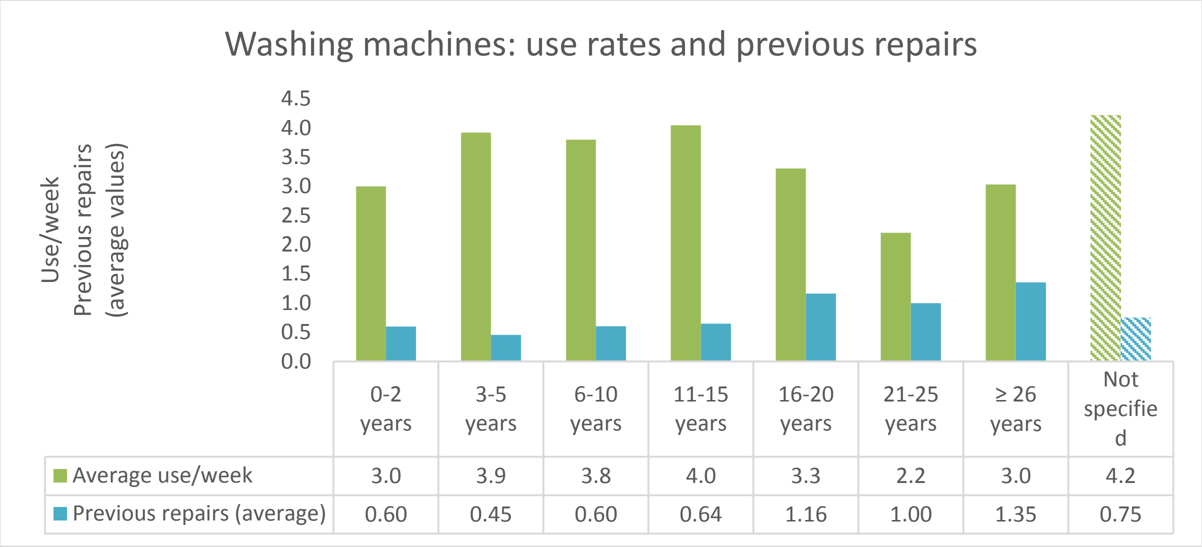


Figure 3.17. Number of repair services for 255 washing machines, with age class and details about the actions undertaken

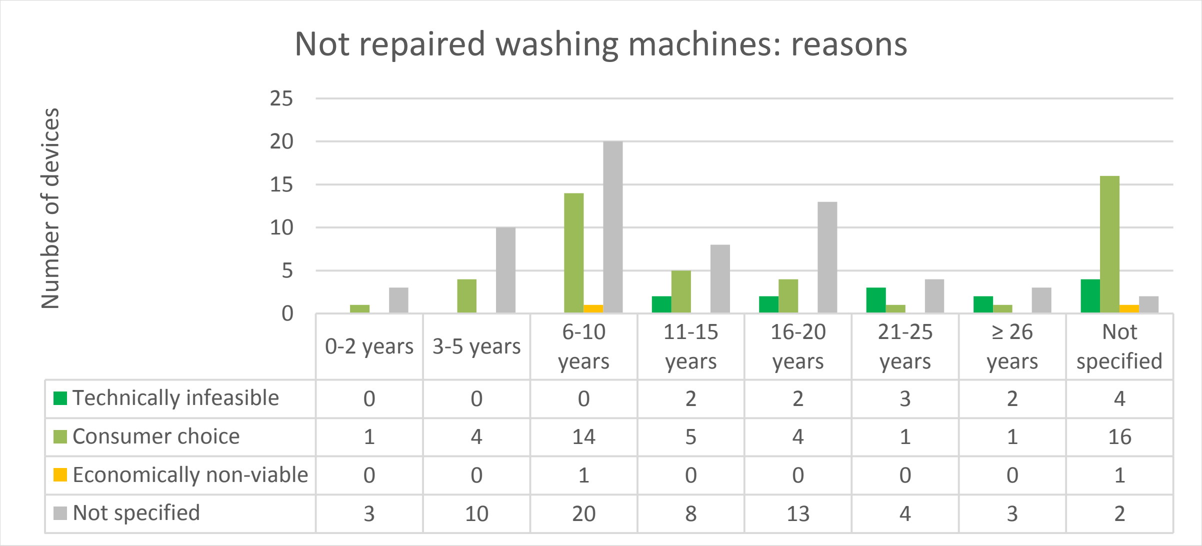


	0-2 years	3-5 years	6-10 years	11-15 years	16-20 years	21-25 years	≥ 26 years	Not specified
Average use/week	3.0	3.9	3.8	4.0	3.3	2.2	3.0	4.2
Previous repairs (average)	0.60	0.45	0.60	0.64	1.16	1.00	1.35	0.75

Figure 3.18. Average use (number of washing cycles/week) and number of previous repairs for diagnosed devices

Figure 3.18 shows the average use rate of washing machines for this subset of data, along with the number of previous repairs. The average number of washing cycles per week declared by clients of R.U.S.Z was about four. Regarding previous repairs, 173 customers declared that their devices had already undergone some repair services before the diagnosis in 2016; nevertheless, the older the device in the dataset, the higher the probability that it had already undergone more than one repair.

Regarding the reasons that prevented the device from being repaired, a significant share was due to the fact that repair was considered too expensive by the customer (Figure 3.19). In particular, for the 6-10-year age class, 40 % of unrepaired devices were classified as too expensive. No failure was explicitly classified as technically infeasible in the age range 0-10 years.



	0-2 years	3-5 years	6-10 years	11-15 years	16-20 years	21-25 years	≥ 26 years	Not specified
Technically infeasible	0	0	0	2	2	3	2	4
Consumer choice	1	4	14	5	4	1	1	16
Economically non-viable	0	0	1	0	0	0	0	1
Not specified	3	10	20	8	13	4	3	2

Figure 3.19. Main reasons not to repair a device, divided by age class.

The analysis conducted on the 2016 subset of data helped to understand the relationships between the age of the device, the use rate and previous repairs with the failure mode diagnosed by technicians. Considering the age of the device, it was possible to highlight the following.

- In the 0-2-year age class four devices of out six were not repaired. Failure modes of unrepaired devices involved the electronics, drum, bearings and engine.
- In the 3-5-year age class more than 50 % of devices were successfully repaired, while only four repairs were considered too expensive by the customer (bearings, engine, shock absorbers and electronics). The main failure modes involved the electronics, the door and detected foreign objects.
- In the 6-10-year age class at least 10 devices required the replacement of carbon brushes. Unrepaired devices had failures principally in the bearings, shock absorbers, drum and tub, and engine.
- In the 11-15-year age class repaired devices mainly required the replacement of carbon brushes and shock absorbers or the removal of detected foreign objects. Unrepaired devices, meanwhile, were mainly diagnosed with multiple failure modes, most involving the bearings and/or shock absorbers.
- In the 16-20-year age class it is again possible to observe successful repairs carried out with the replacement of the carbon brushes and engine maintenance. Failing components preventing repair were again the bearings and shock absorbers (customer choice), doors (locks and seals) and drain pumps.
- Older devices (21-25 years and ≥ 26 years), however, had a rate of repaired devices higher than 50 %, of the total diagnosed devices. The main failure mode concerned the door seals and locks, always successfully repaired. A number of repairs were not possible because of the lack of spare parts (pressure control, electronics).

Overall, the failure modes observed in this subset of data are in line with what is observed in the 2009-2015 database. The main failures were diagnosed in the shock absorbers and bearings (82 cases), doors (77 cases), carbon brushes (56 cases), pumps (51 cases) and electronics (37 cases). Multiple failure modes were observed in about 23 % of cases.

3.2.12. Final remarks

The statistical analysis in this section aimed to raise awareness of failure modes and consequent actions of a wide database of repair services on washing machines. The database was built on a significant sample of data, counting more than 7 000 repair services.

The main results of this study can be summarised in the following key points.

- Multiple failure modes occurred in 30 % of cases. Devices with multiple failure modes were not repaired in 43 % of cases, while devices with single failure modes were not repaired in only 15 % of cases. According to the repair operator, the understanding of the failure modes and how they are interconnected is not straightforward and should be analysed on a case-by-case basis.
- The main failure modes identified during the analysis involved components and parts related to electronics (14 % of cases), shock absorbers and bearings (13.8 %), doors (11.5 %), carbon brushes (9.7 %) and pumps (7.5 %).
- Most repairs were observed for doors (883 cases), carbon brushes (664 cases), pumps (519 cases) and foreign objects (540). The lowest rates (repaired devices over total diagnosed devices with a specific failure mode) were observed for the

drum and tub (27.4 %), electronics (48.7 %) and shock absorbers and bearings (47.4 %).

- About 71 % of the failure modes detected were successfully repaired; for devices that were not repaired, consumer decisions were mainly driven by cost (overall cost, influenced by the spare part cost and the labour), as 78 % of unrepaired devices were ascribable to this reason; the second reason (15 % of unrepaired devices) was technical barriers (spare parts not available, ineffective design for disassembly) that resulted in technically infeasible repair.
- Breaks in bearings were repaired in only 24 % of cases, mainly because of the overall cost of repair. Further analysis should assess opportunities and threats of the design for disassembly applied to the tub bearings.
- Breaks in electronics (generic) were repaired in only 50 % of cases, and control electronics only in 41 % of cases. The main reason not to repair was again cost, but a significant percentage of impossible repairs was registered for control electronics in particular (about 10 %). In this last case, the importance of spare-part availability, software access and updates should be further investigated.

Some additional information was provided by the repair operator on the basis of the experience of technicians. R.U.S.Z observed that the availability and cost of spare parts often play a key role for repair services: an effective design for disassembly would lead to a reduction in working time costs and would therefore make the repair service more convenient for the customer. The cost of spare parts tends to increase, as more components and/or functions are often designed not to be reversibly disassembled (e.g. doors and hinges), and this results in higher prices. Considering medium–low level devices, spare parts are often perceived as too expensive compared to the initial price of the device itself.

The large number of unrepaired bearing failures was mainly observed in washing machines with plastic tubs, where bearings are sealed to the tub; a failure in this component may require the replacement of the part of the tub in which the bearings are contained, or even the whole washing unit (drum, tub, bearings) if the tub consists of one single plastic part. These repair actions usually cost 60-100 % of the washing machine’s original price. The replacement of the bearings can be economically viable when they are sealed into a metallic tub, or screwed to a the tub. If the tub consists of two polymeric parts fastened together, it can be still economically viable to replace only the rear part of the tub together with the sealed bearings.

Access to software for diagnosis by repair operators (including independent operators) was reported as a key element for the correct diagnosis of the failure mode. Without such software some cases were not repaired because, for example: (1) it was impossible to detect the failure mode, (2) the failure mode was detected but it was impossible to test the device or (3) it was impossible to delete the failure code.

Regarding the failure category ‘Electronics’, although the majority of failures were detected at the hardware level, it is expected that there will be an increase in software failures due to the increasing number of functions implemented.

The repair and service centre R.U.S.Z also observed that inappropriate use by customers might lead to early device failures (R.U.S.Z, private communications). The repair centre therefore listed a series of behaviours that should be avoided so as not to compromise the proper functioning of a device:

- unlevelled positioning without using a water-level bubble leads to the early wearing out of shock absorbers and bearings;
- incorrect loading leads to imbalance and wears out the shock absorbers and ruins the bearings;
- overdosage of detergent may block the detergent hose and the drain system;

- the presence of foreign objects in the drain pump filter for a long time may block the pumps;
- avoiding hot water washing cycles may facilitate blockages in the water outlet;
- keeping the door closed between washing cycles can cause the growth of mould (in particular in the door seal);
- lack of proper maintenance (e.g. cleaning of the filters and decalcification).

Preventive measures in this context may help prolong the life of a device.

Particular cases were observed by R.U.S.Z during data collection (R.U.S.Z, private communications). Two cases are reported below to demonstrate that counterintuitive situations may be faced.

- A 33-year-old device brought in for its first repair: the door seal had to be replaced. Repair was judged economically feasible (EUR 210) and spare parts were still available.
- A 4-year-old device brought in for its first repair: the shock absorbers and the bearings had to be replaced. Repair costs: EUR 410.

Future developments

Only one repair operator was tasked with populating the database of repair services, providing robustness and consistency in data collection but limiting the geographical scope of the analysis. Future research will consider the involvement of different operators by using a unique format for data collection and classification.

Future developments will consider the possibility of using interactive tools to display data. This would allow the use of different classifiers (e.g. failure mode, repair yes/no, single/multiple failures, replacement with new/reused components, etc.) simultaneously, depending on the needs of the tool user.

3.2.13. Photo gallery for WM

Figure 3.20. Blocked pressure chamber, possibly as a result of calcification and detergent overdosage

Figure 3.21. Contaminated and calcified heater

Figure 3.22. Worn-out door seal

Figure 3.23. Worn-out carbon brushes (top) — as brushes wear out, they need to be accessible for maintenance or replacement with new carbon brushes (bottom)

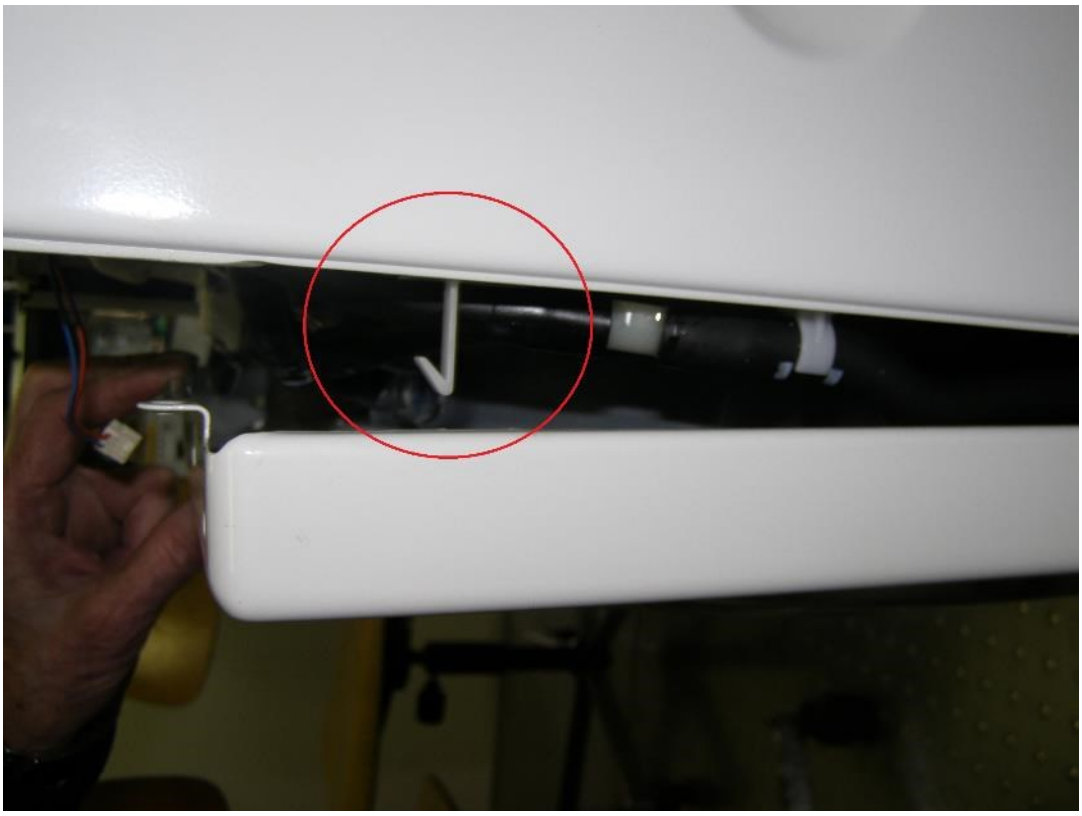


Figure 3.24. Plastic snap-fit used as a connector for the housing of a washing machine (front) — fragile connectors can easily be broken by technicians during repairs or maintenance

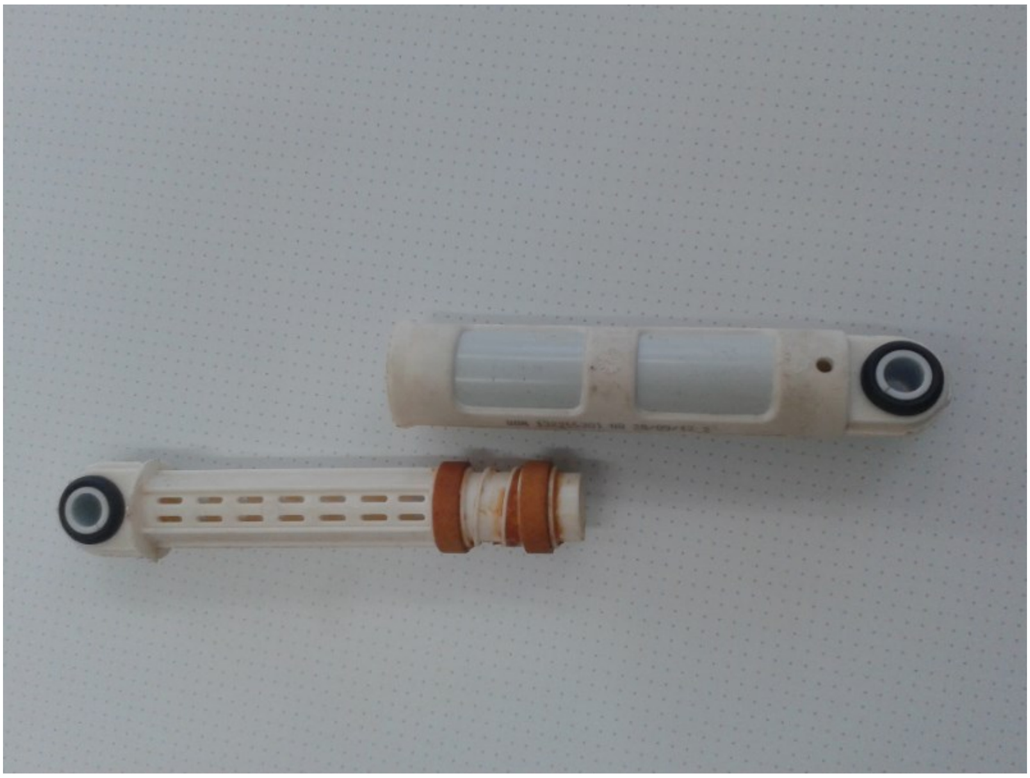


Figure 3.25. Shock absorbers (made of plastics, rubbers and grease) categorised as low-quality by the repair operator.

Figure 3.26. Shock absorbers (made of stainless steel) categorised as high-quality by the repair operator. By using four shock absorbers of this type, shocks are properly prevented and bearings are preserved.

3.3. Repair statistics for dishwashers

Technical barriers[69] already highlighted by Deloitte (2016) for the dishwasher product group are as follows.

- Electronic steering components linked to the timer can fail and it may be difficult to identify the exact failure; these problems were less common in the past when the steering mechanisms were primarily mechanical.
- Failures in the control unit of a dishwasher lead to usually expensive repair costs due to the price of the control unit.
- The increasing use of electronic components in dishwashers means that often the diagnosis of failures has to be done by attaching it to a laptop using specific diagnosis software; the technical documentation and software needed to diagnose the failure are sometimes difficult to access for repair operators that are not official after-sales service providers of the manufacturers.
- In some cases it is difficult to open the casing of the dishwasher and to access the internal components; when the casing is opened at the bottom of the machine troubleshooting is made difficult, since this cannot be done in a stand-up position with the machine turned on.
- Some internal components cannot be accessed and removed easily, e.g. the heating resistors are sometimes fastened and have to be broken to be removed.

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[69] Any product design, choice of materials or difficulty in disassembling the components that may hinder repair is categorised as a 'technical barrier'.

The database provided by R.U.S.Z reports a total of 3 900 repair services (initial diagnoses performed by a technician on a device claimed to be malfunctioning by the owner) registered across 2009-2015, including:

- 84 different brands[70];
- 3 469 services in which technicians detected one or more failure modes;
- 383 services with no failure found[71] by technicians;
- 48 services in which the failure mode was classified as 'unknown' as it was not identifiable.

In the 3 900 repair services, various actions were carried out depending on the initial diagnosis:

- 2 502 cases were successfully completed with a repair action;
- 383 cases with no failure found were excluded, as no actions were carried out by technicians on the device;
- 1 010 services in which repair actions were not performed by technicians due to economic or technical barriers (repair technically infeasible, too expensive/economically infeasible);
- 5 services were classified as 'partial repair' (in case of partial actions for multiple failure modes detected on the device).

The data are shown in the pie charts in Figure 3.27.

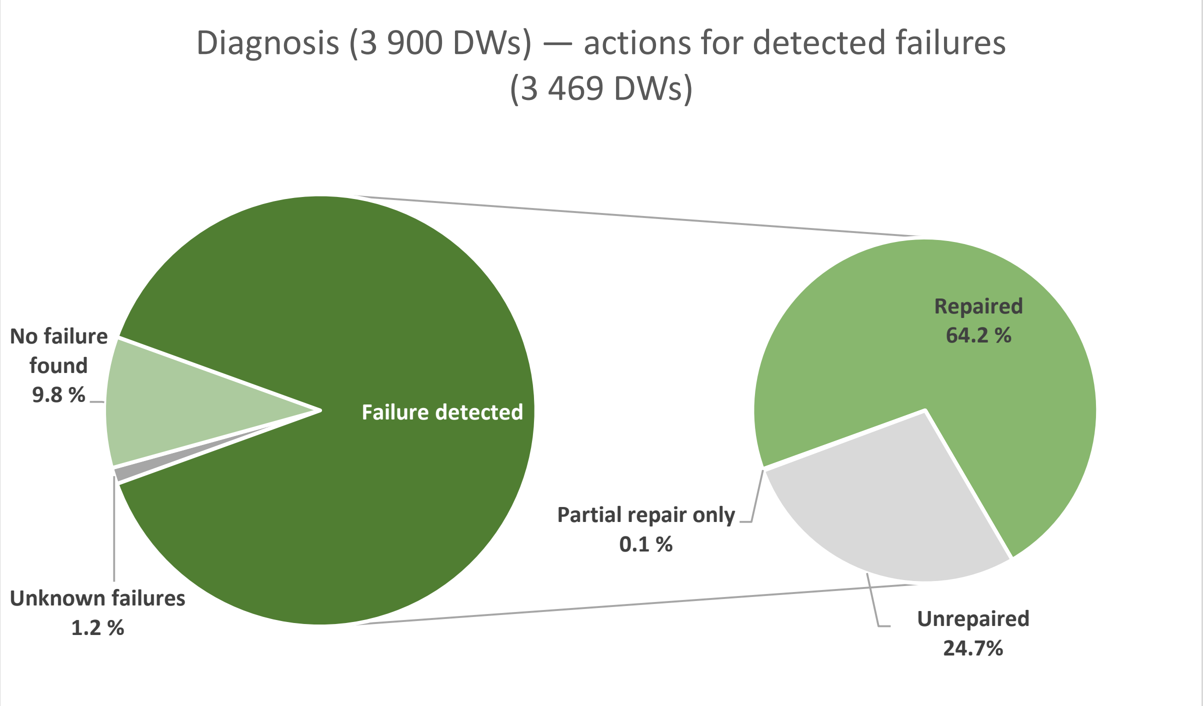

Figure 3.27. Overview of diagnosis for the 3 900 DW and subsequent repair actions if failures were detected (percentages may not total 100 % due to rounding)

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[70] The 'brand' is the commercial name that helps to distinguish a company from its competitors. It may correspond to the manufacturer's name.

[71] 'No failure found' included situations such as: blocked drainage (outside the device/in the wall), water tap closed or defective, power plug off, activated child safety lock, electronics that became wet and dried out in the meantime.

3.3.1. Temporal distribution of repair services

Repair services were recorded from 2009 to 2015. On average about 550 services are provided for dishwashers every year (Figure 3.28).

As in the previous case, a subset of repair services for the first quarter of 2016 was further analysed thanks to additional details provided by R.U.S.Z about recent devices at the moment of the failure. This additional analysis is discussed in Section 3.3.9.

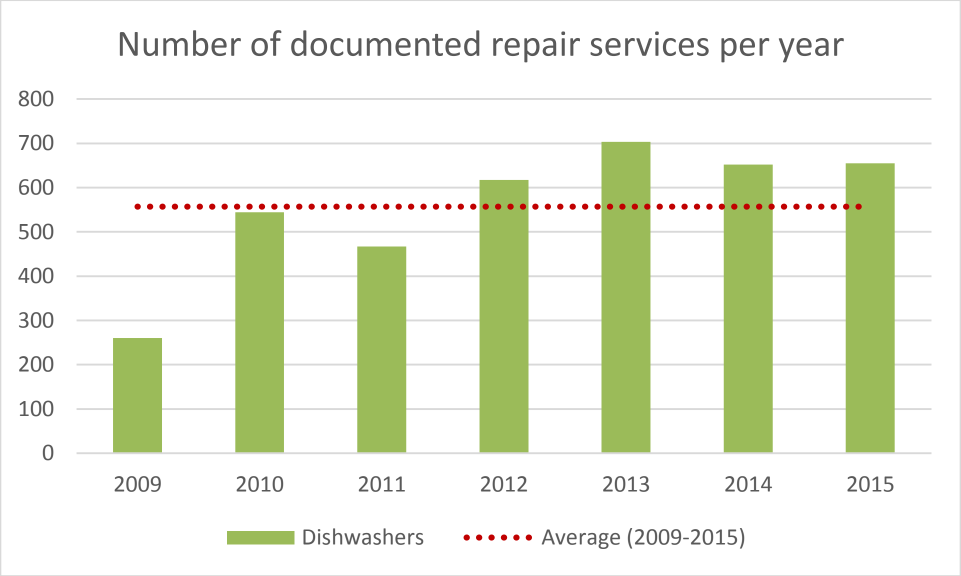


Figure 3.28. Evolution of the documented repair services provided by R.U.S.Z over the 2009-2015 period

3.3.2. Single failure mode vs multiple failure modes

As for the statistical analysis of the washing machine product group, a first classification of datasets was made to divide repair services in which only one failure mode was identified from repair services in which multiple failure modes were detected. In detail:

- single failure mode: one defective component or one failure mode was identified during the diagnosis;
- multiple failure modes: two or more defective components or failure modes were identified during the diagnosis.

Figure 3.29 represents the breakdown between devices diagnosed with single failure mode or multiple failure modes. Multiple failure modes occurred in about 25 % of cases. For these datasets it was not possible to identify which failure mode triggered the others, nor whether there was a clear connection between failure modes on the same device.

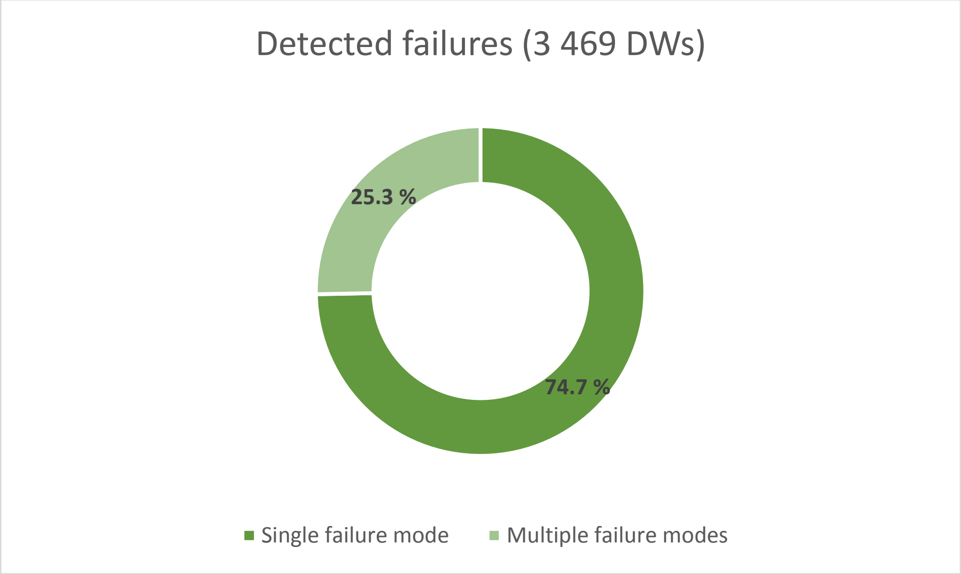


Figure 3.29. Breakdown of repair services in which the device had a single failure mode and multiple failure modes

Devices with multiple failure modes were not repaired in 46 % of cases, while devices with single failure modes were not repaired in only 21 % of cases. This highlights again how multiple failure modes are certainly more difficult to handle, depending on the type of failure mode and on the type of repair (economically feasible or infeasible; technically possible or impossible).

Figure 3.30 gives an overview of the different actions on devices with a single or with multiple failure modes, and it is possible to identify these two different trends. Partially repaired devices (identified in the chart with the label ‘partial’) refer to devices with multiple failure modes, for which the repair was not totally successful, i.e. at least one failure mode was not repaired. This is a relatively small subset of data (five cases), considered as a group of outliers for the statistical analysis.

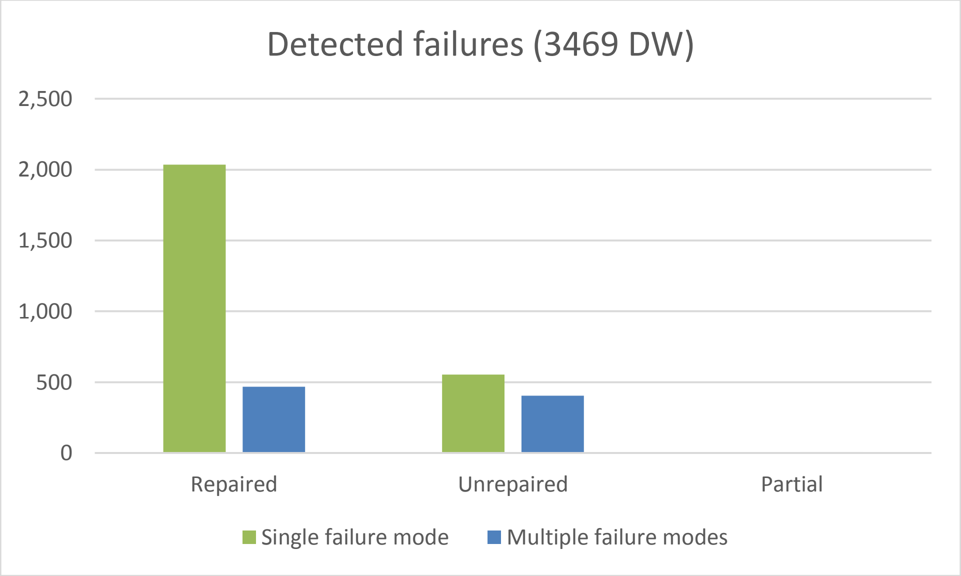


Figure 3.30. Repaired, unrepaired and partially repaired devices, divided by single and multiple failure modes

3.3.3. Identified failure modes

Failure modes were identified by R.U.S.Z and entered into the database of repair services. In order to allow a better overview of results and to identify the main hotspots for the product group, failure modes were categorised and grouped as listed below.

- circulation pumps and drain pumps;
- electronics — control electronics, relays, sensors, program selectors, control panels, displays;
- mechanical or electronic aquastop, other inlet valves, water distributor;
- foreign objects detected in pumps (drain pumps mainly) and drain systems;
- doors, door brakes, handles, hinges, locks and seals;
- drain hose/outlet hoses, drain systems and inlet hoses;
- water tank, salt container and detergent dispenser;
- pressure chamber, pressure control;
- heater, heater plugs and thermostat;
- float switches, micro switches, on-off switches, keypad;
- spray arms and spray arm feed pipes;
- cables and plugs;
- engine, engine condenser;
- other: basket, bearings, filters, program failures, tub leaky, ventilator, wheels, etc.

Group categories were used to limit the number of possible failure modes and to optimise the overview of data. The rationale behind this layout was to group together components with a similar function (e.g. circulation pumps and drain pumps) or parts linked to the functioning of a main device component (e.g. door handles, hinges, locks and seals, all of them key elements of the dishwasher door).

By combining single and multiple failure modes a total of 4 561 specific failure modes were observed in a sample of 3 469 devices (Figure 3.31). Most recurring failure modes involved circulation and drain pumps, electronics (which include control electronics, control panels, program selectors, relays, line filters, etc.), inlet valves and doors (including seals, handles, hinges and locks). Pumps and electronics also represent the greatest number of repaired parts (respectively 20.4 % and 10.9 % of total repairs), but in terms of rate of repairs the most-repaired failure modes were components such as the hose (86 %), the spray arm (85 %) and detected foreign objects (97 %). Overall, 67 % of the identified failure modes were successfully repaired.

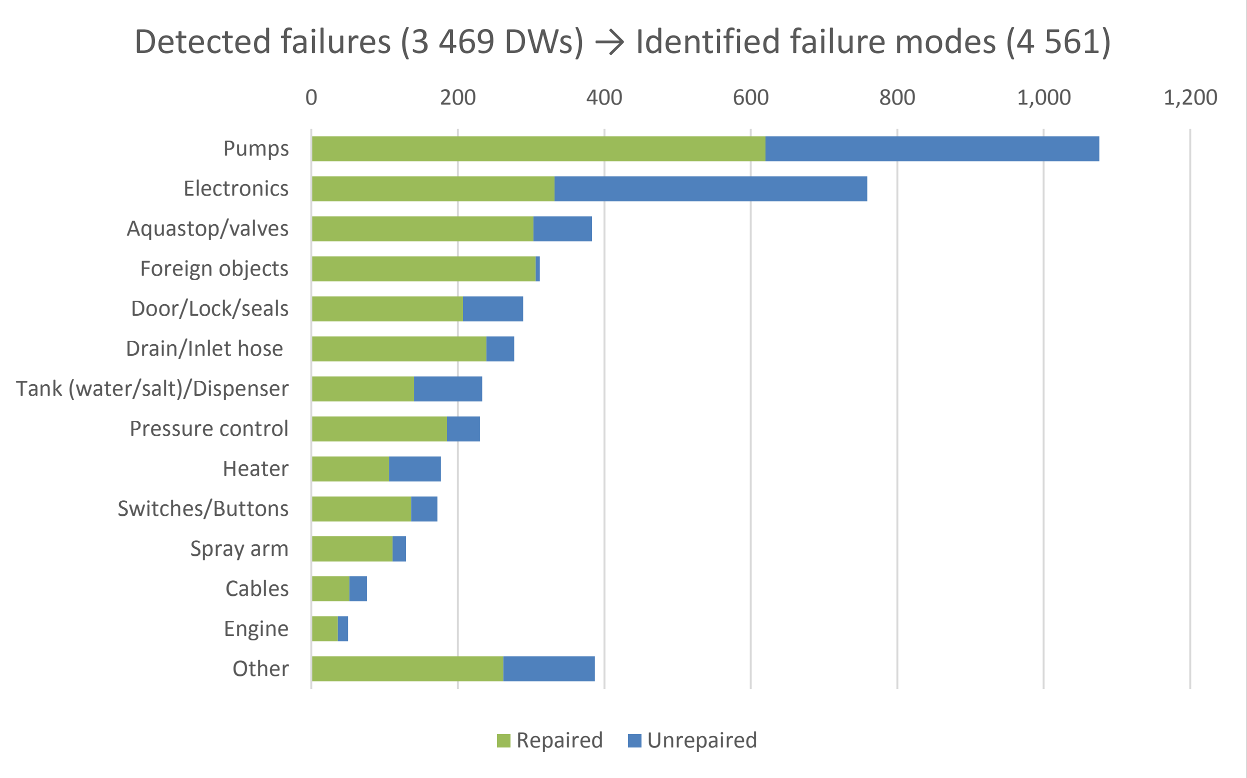


Figure 3.31. 3 469 repair services with detected failures resulted in 4 561 total failure modes — the chart also differentiates between repaired and unrepaired devices

3.3.4. Main reasons not to repair a device

Once again, it is important to analyse which drivers lead to the decision not to repair a device. Only a subset of the database was used for this analysis; repair services with single failure modes were considered for this analysis, as records with multiple failure modes could not provide the same level of detail for each category (decisions cannot always be directly related to a specific failure mode). The main reasons not to repair a DW were divided in three categories.

- Consumer choice: the repair was technically possible but considered too expensive by the customer (considering the overall repair cost, including the cost of the labour and the cost of the spare part(s)).
- Economically not viable: the repair was technically possible but considered economically infeasible by the technician.
- Technically infeasible: the repair was not technically possible. Repairs were impossible for different reasons, mainly because spare parts were not available or because of an ineffective design for disassembly (e.g. clinched, bonded or fused parts; accessibility of the water tank; new-generation circulation pumps where fewer and fewer subcomponents are separable and replaceable, etc.).

Figure 3.32 provides an overview of unrepaired devices, with detail of reasons for each main failure mode. In most cases repairs were possible but considered too expensive by the customer (76 % of the repair services considered). In 17.5 % of cases the repair was classified as technically infeasible, while an economically non-viable repair was reported in only 6.5 % of the considered cases.

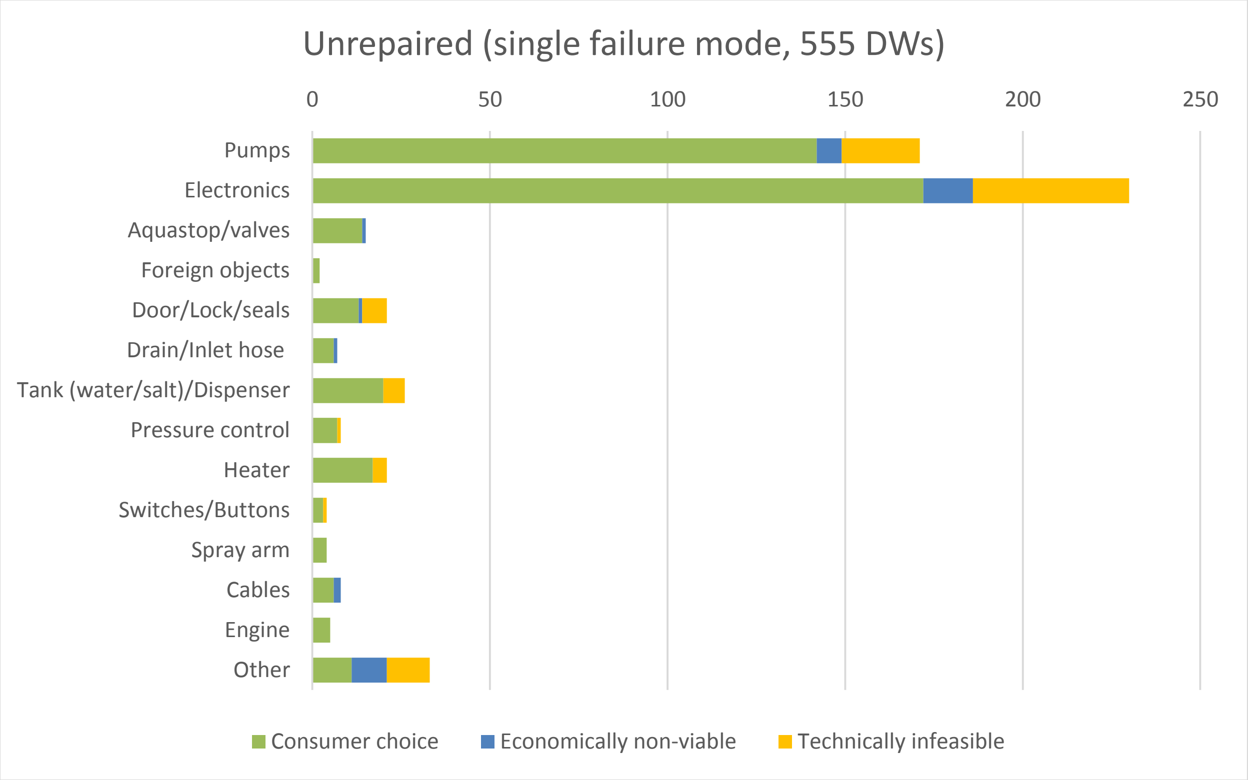


Figure 3.32. Main reasons not to repair a device, categorised by failure mode

3.3.5. Repair services that involved the replacement of a component

As in the previous product group, a further study was carried out to understand which failure modes most often required the replacement of a component. Once again, only a subset of the database with single failure modes was used for this analysis, as datasets with multiple failure modes could not provide the same level of detail. Overall, 2 586 datasets were considered. In about 48 % of cases the repair involved the replacement of a component, while in 30 % of cases it did not require a spare part; the remaining 22 % consists of devices that were not repaired. The failure modes that most often required the replacement of a component were the engine (100 % of repaired devices), aquastop/valves (92 %), switches and buttons (81 %), the heater (79 %) and the door and door parts (76 %). On the other hand, failure modes that did not very often require the replacement of a component were the drain/inlet hose (39 %), the pressure control (39 %), cables (33 %) and, of course, the category of foreign objects detected in the device (3 %).

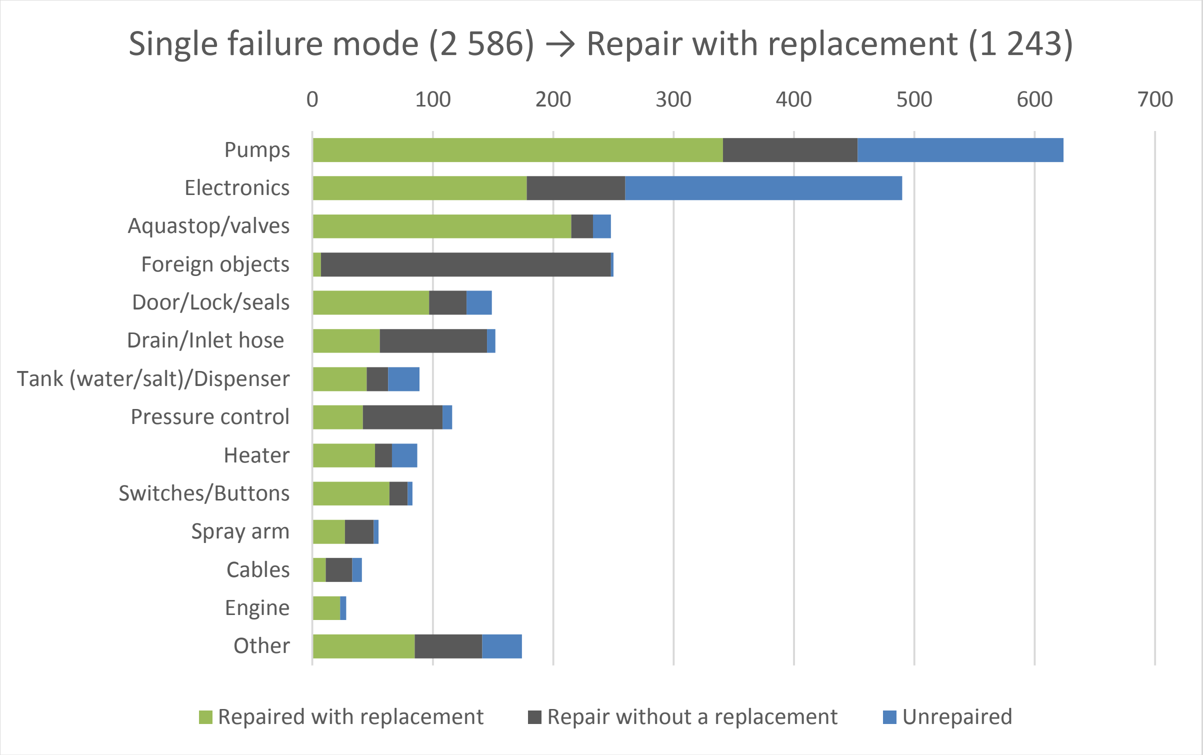


Figure 3.33. Repair services that involved the replacement of a component

3.3.6. Failure category 'Pumps'

Dishwasher pumps represent the most frequently failing component for the dishwasher product group. The failure mode is distributed between single (58 %) and multiple (42 %) failure modes (Table 3.5). Drain pumps are repaired in about 72 % of cases (Figure 3.35). On the other hand, circulation pumps are repaired in only 46 % of the cases considered (Figure 3.34). Repair costs are the main reason not to repair a dishwasher.

Table 3.5. Breakdown of the failure category related to dishwasher pumps (number of identified failure modes) — focus on drain and circulation pumps

Pumps (total)	**Total** **1 078**	**Repaired** **620**	**Unrepaired** **456**	**Partial** **2**
Single failure mode	624	453	171	0
Multiple failure modes	454	167	285	2
Totals	*1 078*	*620*	*456*	*2*
Circulation pumps	629	294	334	1
Drain pumps	432	312	119	1
Not specified	17	14	3	0
Totals	*1 078*	*620*	*456*	*2*

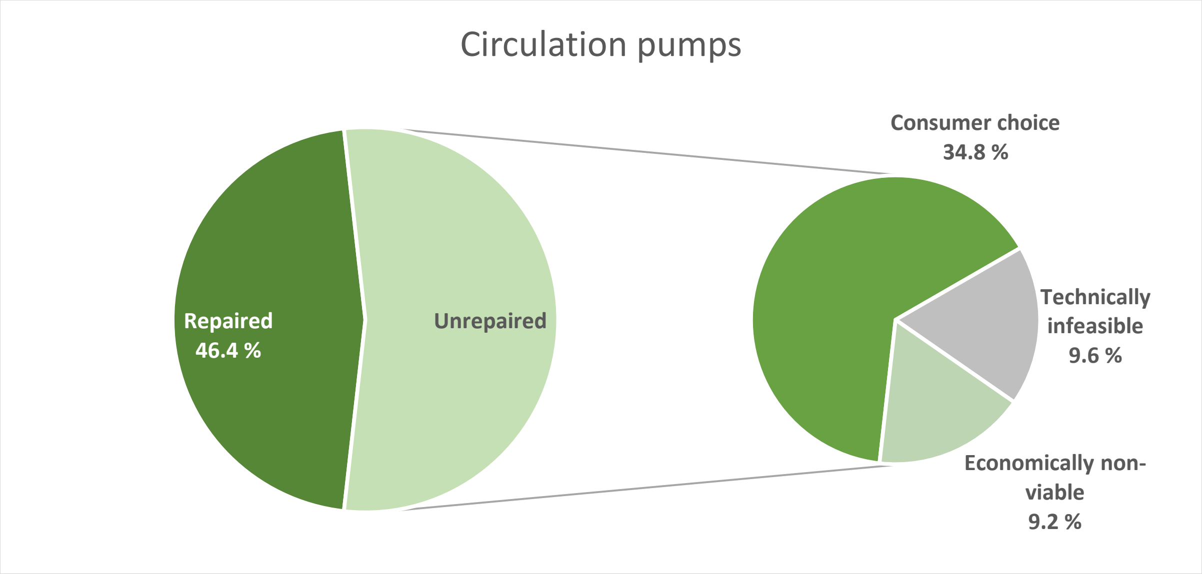


Figure 3.34. Circulation pumps: repaired vs unrepaired

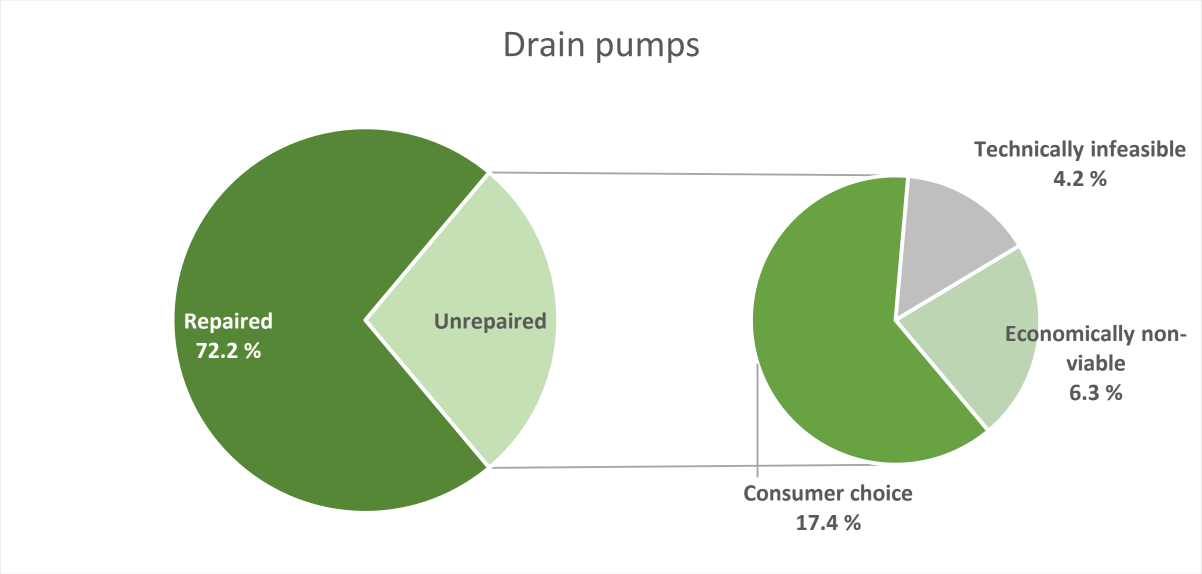


Figure 3.35. Drain pumps: repaired vs unrepaired

3.3.7. Failure category 'Electronics'

Electronics ranked as the second most frequently failing component for the database of dishwashers analysed. The failure category includes various components, such as control electronics, control panel, program selectors, relays, sensors, etc. However, in the majority of cases (52 %), a generic label 'Electronics' was recorded by technicians. 'Control electronics' was listed second with 46 % of cases (Table 3.6); this subgroup includes control electronics, control panels and program selectors. 'Other electronics' includes relays, sensors, fuses, etc. In almost 36 % of cases electronics were involved in multiple failure modes, but, as in the previous cases, it is not clear whether other failure modes caused an electronic failure or vice versa. Repairs in this category were generally difficult: only 32.5 % of cases for the 'Control electronics' category and 51 % for unspecified 'Electronics' (Figure 3.36 and Figure 3.37).

Table 3.6. Breakdown of the failure category related to dishwasher electronics (number of identified failure modes).

Electronics (total)	**Total** **761**	**Repaired** **332**	**Unrepaired** **427**	**Partial** **2**
Single failure mode	490	260	230	0
Multiple failure modes	271	72	197	2
Totals	*761*	*332*	*427*	*2*
Control electronics	347	113	233	1
Electronics (unspecified)	397	204	193	0
Other electronics	17	15	1	1
Totals	*761*	*332*	*427*	*2*

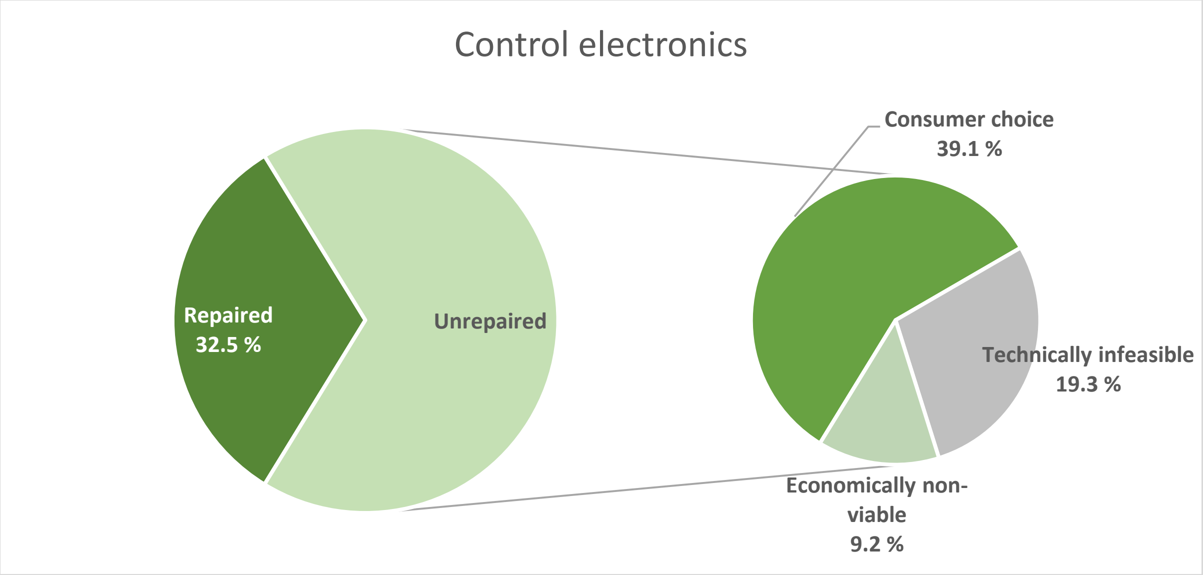


Figure 3.36. Control electronics: repaired vs unrepaired

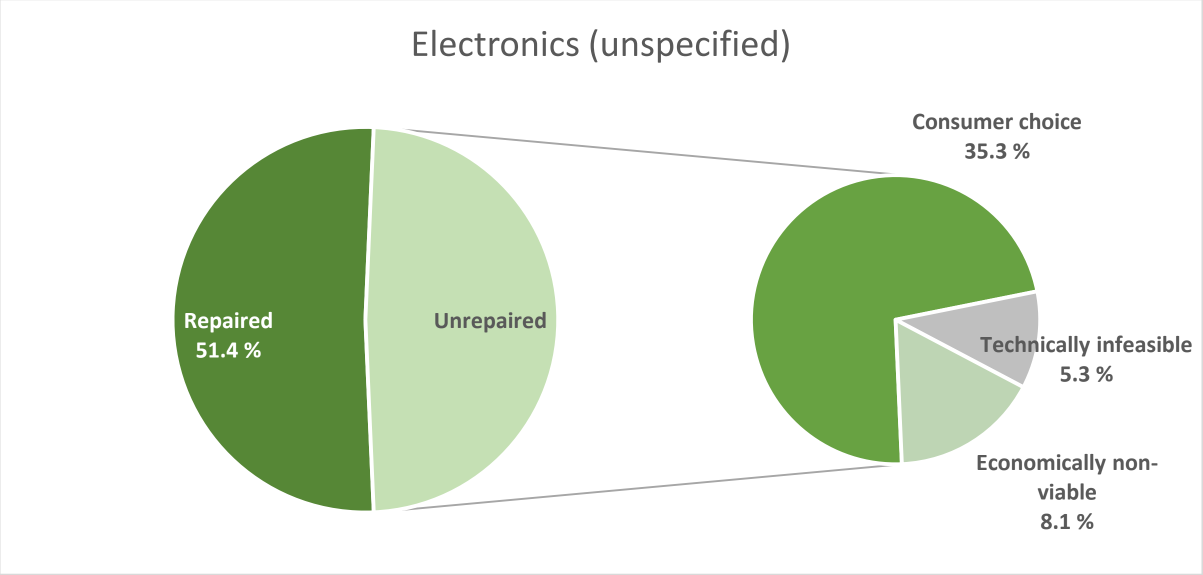


Figure 3.37. Electronics (unspecified): repaired vs unrepaired

3.3.8. Spare parts: new components or reused components

As in the previous case, this analysis concerns the use of new or reused components to replace a defective dishwasher part. Only single failure modes were considered for this analysis, as datasets with multiple failure modes could not provide the same level of detail for each category. Out of 2 035 cases that had been successfully repaired, 1 241 cases required the replacement of a defective component: 1 146 records involved the use of a new component, while 95 cases could take advantage of a reused component, i.e. a dishwasher part extracted from another device.

In absolute values, reused components were mainly used to replace pumps, electronics and aquastop/valves; nevertheless, the highest relative percentages of reused components are for the water tank/detergent dispenser, pump, spray arm and heater categories, each at more than 10 % (Figure 3.38).

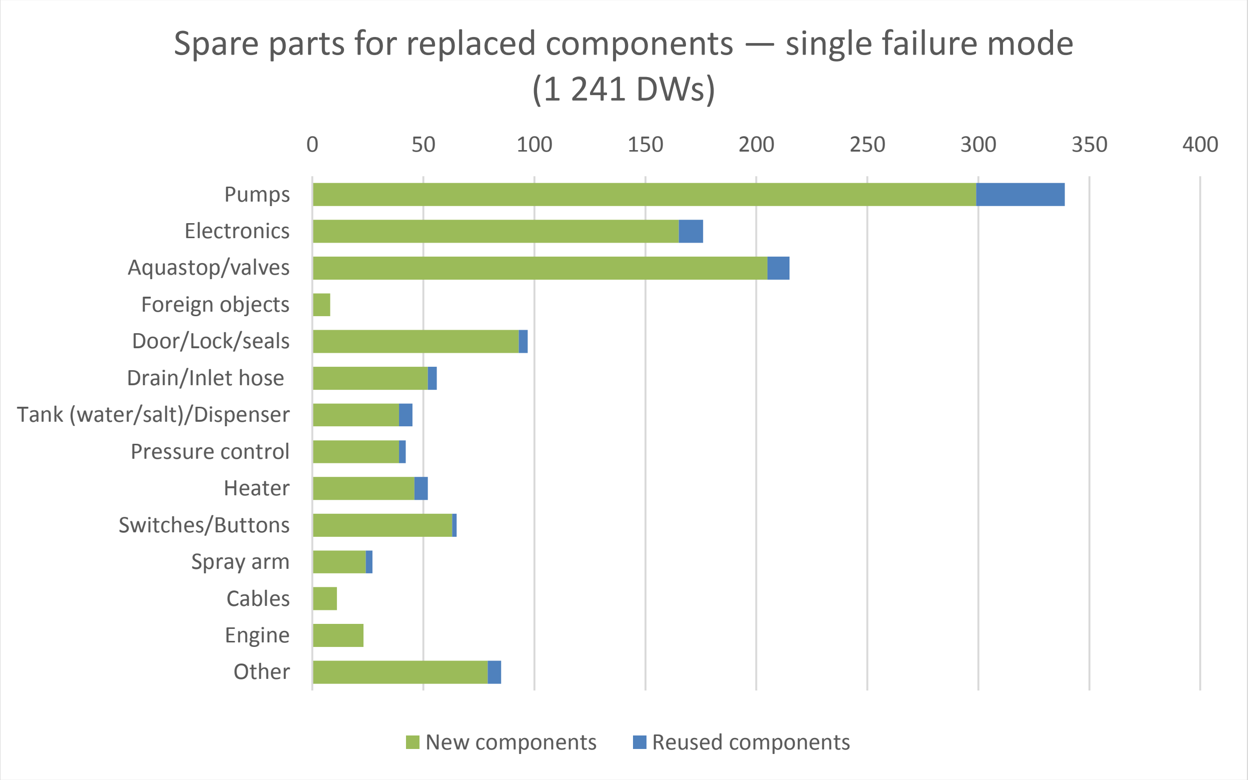


Figure 3.38. New and reused components used as spare parts for replacements

3.3.9. Detailed analysis on the 2016 data subset

As mentioned in Section 3.3.1, an additional analysis was performed on a subset of repair services occurring in the first quarter of 2016 thanks to a more detailed questionnaire used to classify devices at the moment of failure. Additional information included in the questionnaire was the same as that defined for the WM case study:

- the age of the device at the moment of the repair service;
- the average use rate by the user (washing cycles/week);
- the number of previous repair services (if any).

The age of the device at the moment of the repair service was then classified into different groups:

- 0-2 years
- 3-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- 21-25 years
- ≥ 26 years
- not known/did not answer.

A total of 262 DW constitutes the 2016 database. In 141 cases the customer was able to answer the three questions mentioned above. Figure 3.39 gives an overview of the 141 devices classified with the more detailed questionnaire. Even though the majority of them were brought to R.U.S.Z in the 3-5-year (41 devices) and 6-10-year (43 devices) age classes, the average age of the device brought to R.U.S.Z was 10.6 years (this value cannot be considered as an estimation of the lifetime of the device). In the 0-2-year age class only one device was diagnosed, but no failures were found by the operator, resulting in an unnecessary repair service. Considering mean values, it emerged that:

- 11.9 years is the average age of devices that had already had at least one previous repair at the moment of the diagnosis;
- 9.9 years is the average age of devices that had never had a previous repair at the moment of the diagnosis;
- 10.3 years is the average age of devices successfully repaired by repair centre operators;
- 12.0 years is the average age of devices not repaired by repair centre operators.

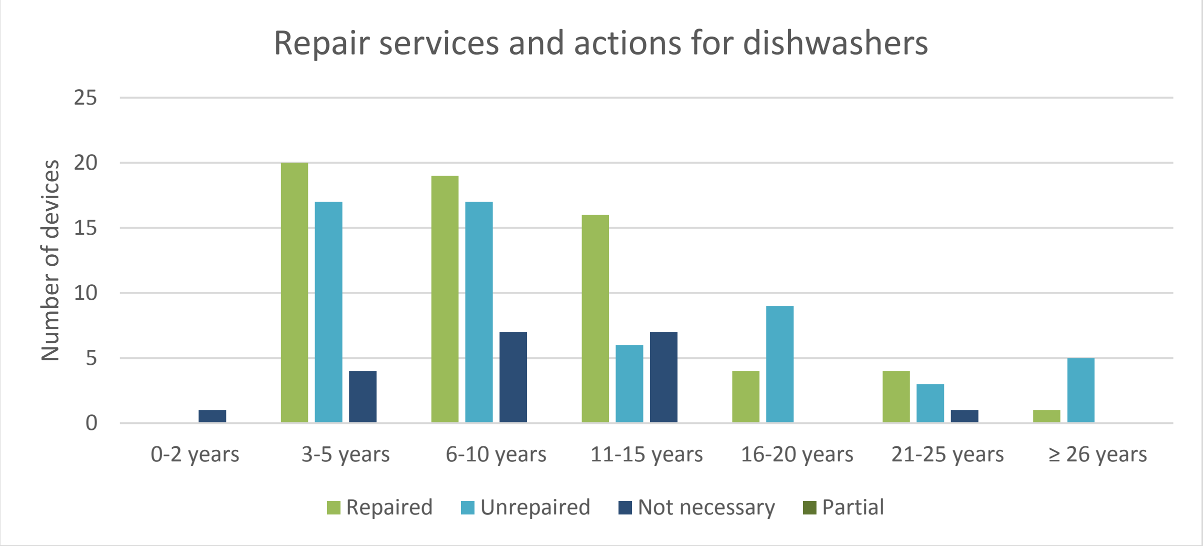
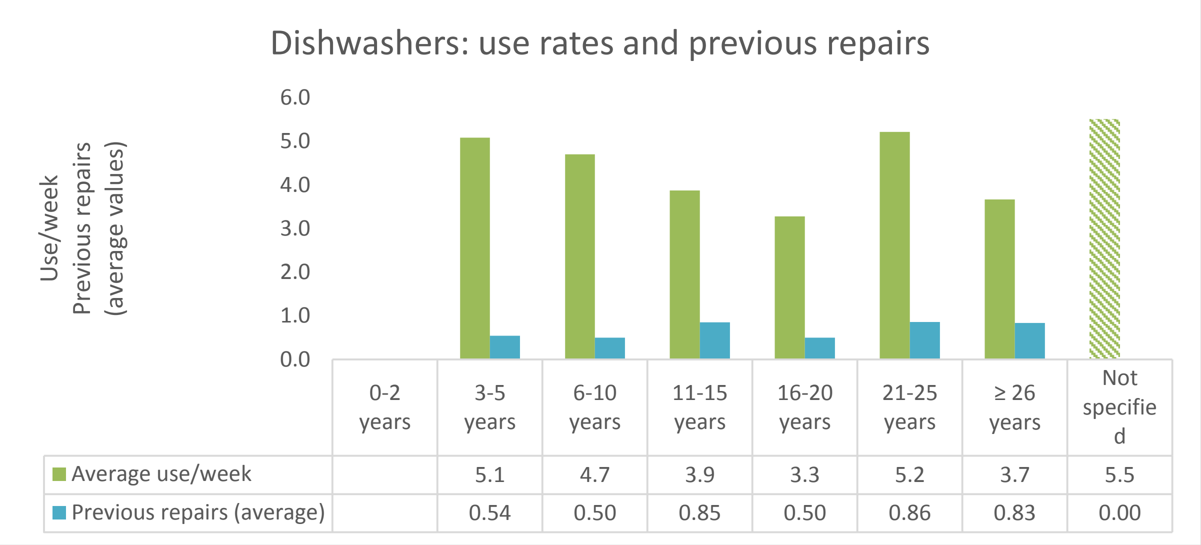


Figure 3.39. Number of repair services for 141 dishwashers, with age class and details about the actions undertaken

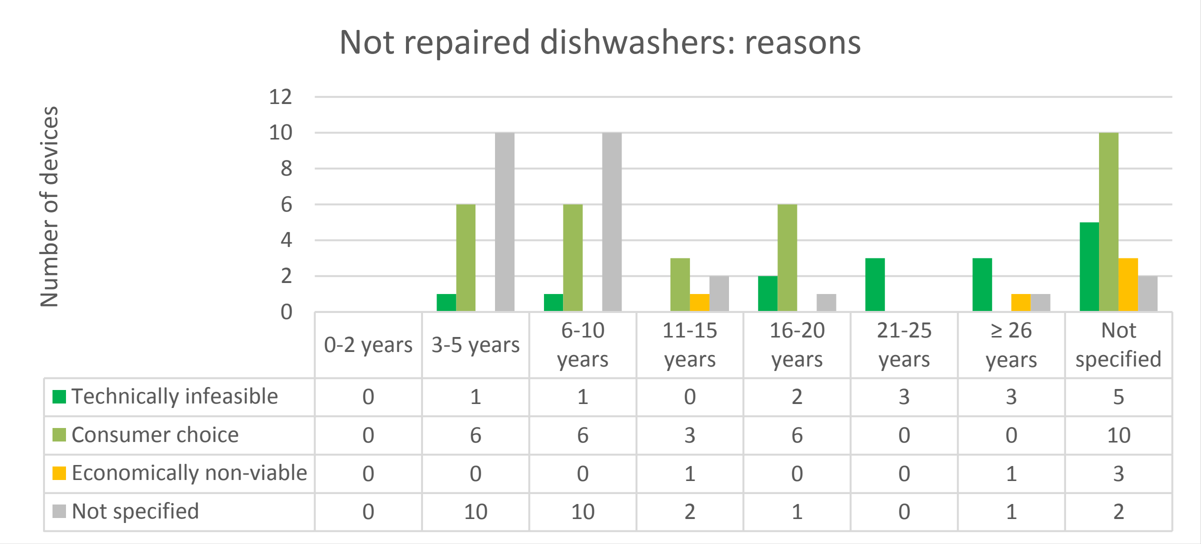
Figure 3.40 shows the average use rate of dishwashers for this subset of data, along with the number of previous repairs. The average the number of washing cycles per week declared by clients of R.U.S.Z was about 4.5. Regarding previous repairs, 65 customers declared that their devices had already undergone some repair services before the diagnosis in 2016. There is no clear trend for previous repairs. For washing machines (Section 3.2.11), the older the device of the considered dataset the higher the probability that it had already undergone more than one repair service; for dishwashers, the highest average values (0.83-0.86 repairs/device) were observed in the 11-15-year, 21-25-year and ≥ 26-year age classes, while there were low average values (0.50-0.54 repairs/device) in the 3-5-year, 6-10-year and 16-20-year age classes.



	0-2 years	3-5 years	6-10 years	11-15 years	16-20 years	21-25 years	≥ 26 years	Not specified
🟩 Average use/week		5.1	4.7	3.9	3.3	5.2	3.7	5.5
🟦 Previous repairs (average)		0.54	0.50	0.85	0.50	0.86	0.83	0.00

Figure 3.40. Average use (number of washing cycles/week) and number of previous repairs for diagnosed devices.

Regarding the reasons that prevented the device from being repaired, the main explanation was the cost of repair, as the proposed repair was not finalised due to a customer choice (Figure 3.41). This reason is particularly present in younger devices (3-5 years and 6-10 years, with six devices for each age class). Devices that were not repaired because of a technically infeasible repair were mainly observed for older DW (16-20, 21-25 and ≥ 26 years), even though two failures were explicitly classified as impossible in the 0-10-year age range and concerned the electronics (8-year-old device) and the heater (5-year-old device).



	0-2 years	3-5 years	6-10 years	11-15 years	16-20 years	21-25 years	≥ 26 years	Not specified
🟩 Technically infeasible	0	1	1	0	2	3	3	5
🟩 Consumer choice	0	6	6	3	6	0	0	10
🟨 Economically non-viable	0	0	0	1	0	0	1	3
⬜ Not specified	0	10	10	2	1	0	1	2

Figure 3.41. Main reasons not to repair a device, divided by age class.

Also for this product group, the analysis conducted on the 2016 subset of data helped to understand the possible relationships between the age of the device, the use rate and previous repairs with the failure mode diagnosed by technicians. Considering the age of the device, it was possible to highlight the following.

- In the 0-2-year age class only one device was registered, but no failure was found by technicians. It is not possible to conclude that in the first quarter of 2016 no other devices were diagnosed, as about 46 % of clients did not provide information about age of the device at the moment of repair.
- In the 3-5-year age class about 50 % of devices were successfully repaired. Only one repair was considered technically infeasible (spare part for a heater not available for a 5-year old device), while six repairs were considered too expensive by the customer (heaters, electronics, engine and circulation pump). Most recurring failure modes involved the electronics, the heater and the spray arm.
- In the 6-10-year age class four devices with defective drain pumps were not repaired because of the cost of the spare part and repair (customer choice). Other recurring failure modes concerned the drain hose (all of them repaired) and the pressure control (repaired in 50 % of cases).
- In the 11-15-year age class repaired devices mainly required the removal of detected foreign objects. Other recurring failure modes involved the circulation pump (three cases, not repaired by customer choice), the drain pump (two cases successfully repaired) and the electronics (four cases, only one not repaired because too expensive according to the customer).
- In the 16-20-year age class only three devices (program failure, hose and keypad replacement) out of 13 were repaired. Two repairs were technically infeasible (no circulation pump or door handle available) and six repairs were declined by customers (for devices in the 18-20-year age class), concerning electronics, circulation pumps, engine and water tank.
- Older devices (21-25 years and ≥ 26 years), however, had a rate of repair lower than 36 %, out of the total diagnosed devices (removal of foreign object and replacement of the aquastop). Six failure modes were considered technically not possible (electronics, circulation pumps, hinges and switches) and one economically non-viable (multiple failure modes related to drain pump and inlet valve).

Overall, the failure modes observed in this subset of data are aligned with what was observed in the 2009-2015 database. The main failures were diagnosed in pumps (50 cases), electronics (36 cases), doors (27 cases) and detected foreign objects (24 cases). Multiple failure modes were observed in about 16 % of cases.

3.3.10. Final remarks

The statistical analysis in this section aimed to raise awareness of failure modes and consequent actions of a wide database of repair services on dishwashers. The database was built on a significant sample of data, counting 3 900 repair services in the 2009-2015 period and about 260 in the first quarter of 2016. The main results of this study can be summarised in the following key points.

- Multiple failure modes occurred in 25 % of cases. Devices with multiple failure modes were not repaired in almost 46 % of cases, while devices with single failure modes were not repaired in only 21 % of cases. According to the repair operator, the identification of the failure modes and how they are interconnected is not straightforward and should be analysed on a case-by-case approach.
- The main failure modes identified during the analysis involved components and parts related to the pumps (almost 24 % of cases), electronics (16.7 %), aquastop/valves (8.4 %), foreign objects (6.9 %) and doors (6.4 %).
- Most repairs were observed for pumps (620 cases), electronics (332 cases), aquastop/valves (303 cases) and foreign objects (306). The lowest rates

(repaired devices over total diagnosed devices with a specific failure mode) were observed for pumps (less than 58 %) and electronics (less than 44 %).

- Almost 67 % of the detected failure modes were successfully repaired. However, 'consumer choice' was classified as the main reason not to proceed with a repair action (76 % of devices not repaired). Another important reason (17.5 % of devices not repaired) was technical barriers (spare parts not available, ineffective design for disassembly) that resulted in a technically infeasible repair.
- Breaks in circulation pumps were repaired in about 46 % of cases, mainly because of the cost of repair (overall cost including spare parts and labour). Defective drain pumps, however, were repaired in more than 72 % of cases. Further analysis should evaluate the possibility of increasing the percentage of repair for circulation pumps. The tendency is to design and use more complex and sensitive circulation pumps, to be aligned with additional programs controlled by the electronics. This results in higher costs and more challenging repairs, as it may be that the replacement of the electronic board also requires the replacement of the whole circulation pump.
- Breaks in electronics (generic) were repaired only in 51 % of cases, and in control electronics in less than 33 % of cases. The main reason not to repair was again the overall cost (consumer choice), but a considerable number of technically infeasible repairs were registered for control electronics in particular (about 19.3 % of cases). In this last case, the importance of the availability of spare parts, software access and updates should be further investigated.

Some additional information was provided by the repair operator on the basis of the experience of technicians (see Section 3.2.12 for issues faced due to the design of components, access to diagnosis software and electronics problems). The repair and service centre R.U.S.Z also observed that inappropriate use by customers might lead to early device failures (R.U.S.Z, private communications). The repair centre therefore listed a series of behaviours that should be avoided so as not to compromise the proper functioning of a device:

- the extensive adoption of low-temperature programs, as well as insufficient use/no use of detergents, may lead to fat deposition;
- excessive leftovers/scraps on dishes may block filters and drain pump;
- broken/damaged glasses and/or dishes may block filters and pumps;
- cutlery and big dishes, if not well positioned inside the device, may block or even damage the spray arms;
- lack of proper maintenance by users (e.g. cleaning of the filters and decalcification).

Preventive measures in this context may help prolong the life of a device. Particular cases were observed by R.U.S.Z during the data collection (R.U.S.Z, private communications). Two cases are reported below to demonstrate that counterintuitive situations may be faced.

- A 29-year-old device brought in for its second repair: a foreign object was detected and had to be removed from the pump. Repair was carried out as it was economically feasible (EUR 120).
- A 2-year-old device brought in for at its first repair: the electronics were defective. Repair was too expensive (EUR 390) and judged infeasible by the customer.

Future developments. Only one repair operator was tasked with populating the database of repair services, providing robustness and consistency in data collection but limiting the geographical scope of the analysis. Future research will consider the involvement of different operators by using a unique format for data collection and classification, and the possibility of using interactive tools to display data.

3.3.11. Photo gallery for DW

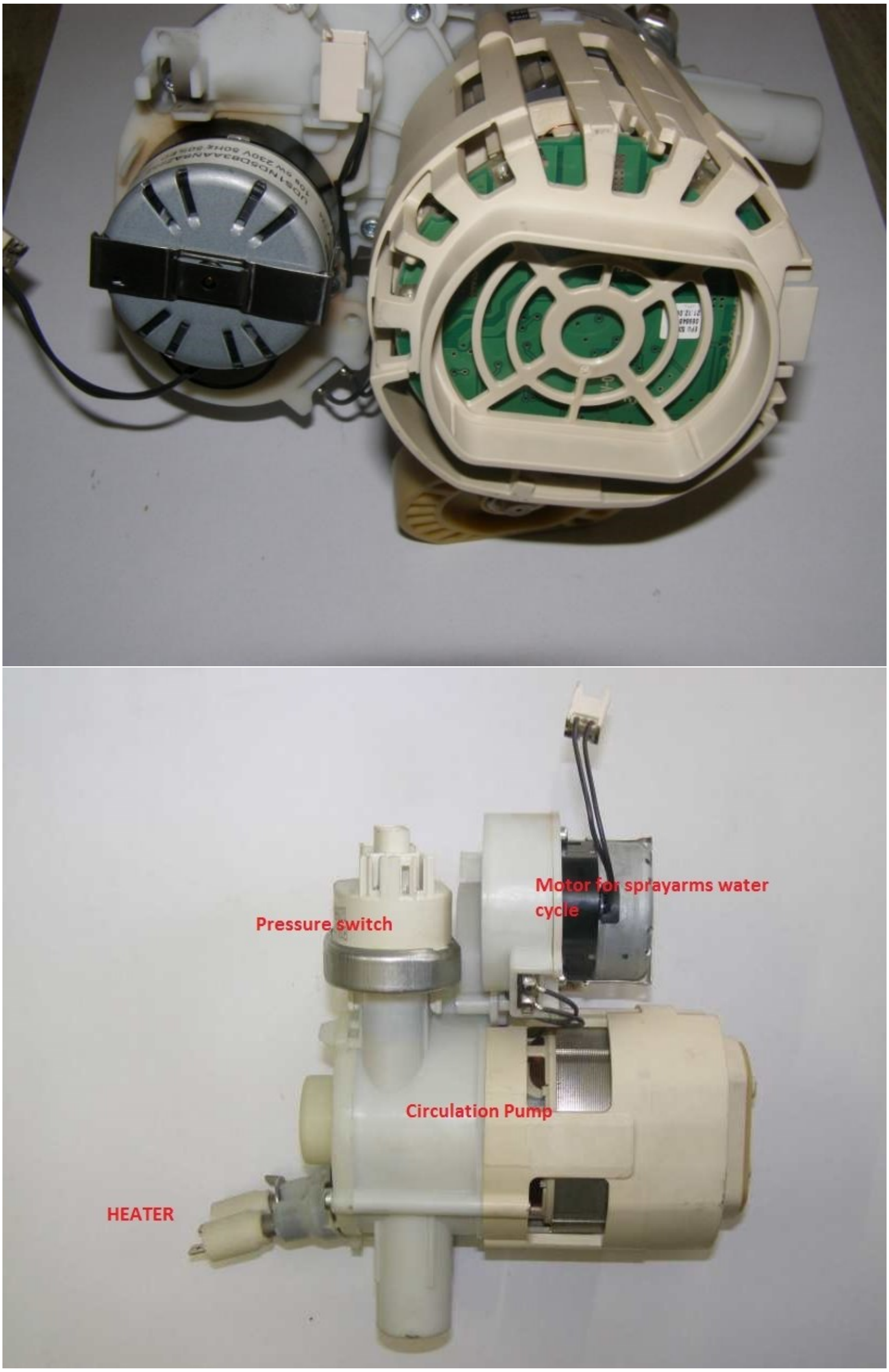


Figure 3.42. Circulation pump with electronic board — in case of failure, only the heater and the pressure switch can be replaced separately; the repair of other parts requires the replacement of the whole unit.

Figure 3.43. Circulation pump without electronic board — seals, pump, heater and motor are separable and their replacement does not require the whole unit to be replaced.

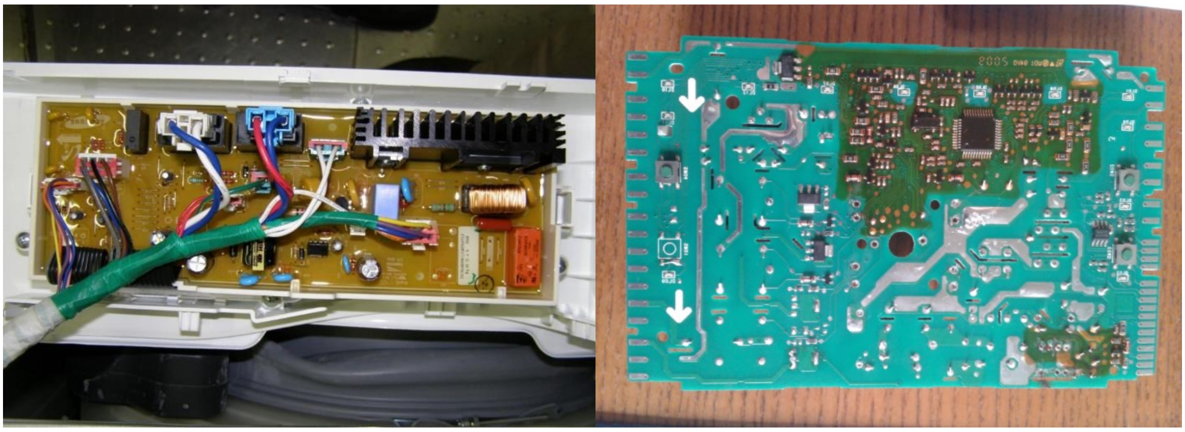


Figure 3.44. Resin layer electronic — technicians generally replace the whole board, but repair or substitution of components on the printed circuit board are possible. In some cases, resin coated PCBs (PCB on the left side and dark-green area of the PCB on the right side) are impossible to repair, as this type of layer cannot be re-soldered and components cannot be replaced, in case of failure.

Conclusions and recommendations

The report introduced and discussed various evidence related to the durability, repair and reuse of washing machines and dishwashers. Based on these outcomes, the following sections introduce a series of concluding remarks and recommendations aiming at improving the durability, reusability and reparability of these products. These recommendations can support the identification and introduction of policy measures for more durable and reusable products in the EU market.

Recommendations to improve the durability of WM and DW

The analyses carried out in the first chapter of this report proved that prolonging the lifetime of WM and DW is environmentally convenient in the majority of the scenarios considered. Product policies should encourage the design of durable products.

A strategy to address the durability of WM and DW would be the setting of minimum lifetime requirements, namely the average expected lifetime or the average number of washing cycles. This has been underlined also by other recent studies, which investigated durability issues for other products (Ricardo-AEA, 2015; Montalvo et al., 2016). However, no standard has been identified to measure the durability of these product groups. Suitable standards should introduce methods that are not excessively lengthy or costly to comply with. On the other hand, the design of durable products and the assessment of their lifetime has been recognised as crucial by several manufacturers, as proved by lifetime claims used for the commercialisation of these products (Ardente and Talens Peiró, 2015). Manufacturers generally perform durability tests on samples before and after putting them on the market. Analogously, some associations of consumer perform tests on products in order to check their durability and performances. Lifetime tests can be run with a defined series of washing cycles in order to simulate wear during real-life conditions. Alternatively, accelerated life tests are also performed by running washing cycles with overstressed conditions, in order to test the reliability and robustness of specific parts or functions of the device. It is therefore recommended that future research focus on the development of standardised procedures to test the durability of WM and DW. Initiatives to set out design standards for the durability of products already demonstrate that the development of standards and their transposition to the single market can take decades (Montalvo et al., 2016). Exemplar procedures developed by manufacturers could be used as a starting point to initiate the development of such standards.

Specific standards for endurance tests are available for the testing of certain components of the machines. Box A below lists some standardised endurance tests for certain components of WM, including the target component, the available reference standards and the number of actuation/operation cycles, which the component should comply with.

Box A. Existing standardised endurance tests for components

- Switches (IEC 60335-1), 10 000 cycles of actuation.
- Automatic controls (IEC 60335-1), 30–10 000 operation cycles, depending on the function.
- Openings (IEC 60335-2-7), 10 000 opening and closing cycles.
- Braking mechanism (IEC 60335-2-7), 1 000 cycles.
- Internal wiring (IEC 60335-1), 100 flexing cycles, for conductors flexed during maintenance.

Another recommendation consists of promoting the provision of relevant information and suggestions to improve product lifetime. Examples of fundamental suggestions are provided hereinafter, based on statistics about common failures of WM and DW as described in Chapter 3. It is remarked that this information is generally already reported in user manuals, however the links of such behaviour with a longer lifetime of the product are not clearly highlighted. Moreover, it is necessary to standardise how this information should be reported. Having such information conveyed through a dedicated section on durability could be more effective for users.

Box B. Example of information for users promoting the durability of WM and DW

Relevant information for the durability of products could be provided in the user manual, for example in a dedicated section on the 'Durability of the product', including relevant information about the proper use and maintenance of the products and risks associated with improper behaviour [72].

For example, for washing machines, the manual could mention that [73]:

- unlevelled positioning without using a water-level bubble leads to early wearing out of shock absorbers and bearings;
- incorrect loading leads to imbalance and wears out the shock absorbers and ruins the bearings;
- overdosage of detergent may block the detergent hose and the drain system;
- the presence of foreign objects in the drain pump filter for long time may block the pumps;
- avoiding hot water washing cycles may facilitate blockages in the water outlet;
- keeping the door closed between washing cycles can cause the growth of mould (especially in the door seal);
- lack of proper maintenance by users could lead to breaks (e.g. cleaning of the filters and decalcification).

For example, for dishwashers, the manual could mention that [74]:

- the extensive adoption of low-temperature programs may lead to fat deposition;
- excessive leftovers/scraps on dishes may block filters and drain pump;
- broken/damaged glasses and/or dishes may block filters and pumps;
- cutlery and big dishes, if not well positioned inside the device, may block or even damage the spray arms;
- lack of proper maintenance by users could lead to breaks (e.g. cleaning of the filters and decalcification).

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[72] Information on the product's durability is generally provided by manufacturer. However, providing this information in a systematized and organized way could allow the consumer to realize how the product lifetime is strictly linked to the user behaviours, and that the adoption of good practices can contribute to the extension of the product lifetime.

[73] These aspects have been pointed out by the repair company as those affecting a large number of WM failures, as discussed in Section 3.2.12.

[74] These aspects have been pointed out by the repair company as those affecting a large number of DW failures, as discussed in Section 3.3.10.

The improvement of the durability of WM and DW could also be promoted through additional recommendations to improve the reparability and reusability of the products, as described below.

Recommendations to improve the reparability of WM and DW

The statistical analysis of common failures for WM and DW, as discussed in Chapter 3, identified parts and components that frequently failed (i.e. failure modes) in devices. The statistics also included figures on the type of repair and the need for replacement. These statistics could be used to focus the attention of the product design in order to reduce these failure modes and facilitate product repair. A possible strategy would be to improve the design for disassembly of the devices, in order to facilitate access, disassembly and repairing/replacement of specific components. Box C summarises the components of WMs and DW the reparability of which is crucial for product durability.

Box C. Improving the reparability of WM and DW

Products should be designed so that the following components (when present) can be reversibly disassembled (without damaging the removed components or other product components), in order to be replaced or repaired (including cleaning) and reassembled.

For WMs [75]:

- shock absorbers;
- electronics — control electronics, engine electronics/inverter electronics, relays, program selectors or control panels, line filters, displays;
- doors, door handles, hinges, locks and seals;
- engine and carbon brushes, drive belt;
- drain pumps;
- heater[76]
- pressure chamber/air hose (for cleaning) and pressure control;
- inlet valves, aquastop (mechanical or electronic);
- drain hose and inlet hoses

Bearings could be also added to this list, since they are some of the components that fail most often and that, when repaired, can still grant a large additional lifetime to the machine (Section 3.2.3). However, as shown in the report, there are different design alternatives for the fastening of the bearings to the tub[77] and for the design of the tub[78] itself. This implies a wide variation of the efforts (and costs) about the disassembly and replacement of the bearings and also about the effectiveness of the repair[79] (Section 2.6.3.2).

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[75] This list includes components that fail and are repaired most frequently in WM, as discussed in Section 3.2.3.

[76] Accessibility of the heater is important for replacement and measurement

[77] Bearings can be sealed to the tub or screwed (solution adopted in some vertical load WMs).

[78] For example, the tub can be made by stainless steel or plastics, and can be produced as single piece or two pieces fastened together.

[79] The disassembly of the bearings is generally a difficult and long process, which requires the disassembly of large part of the machine. Moreover, the replacement of bearings has to be carefully performed to avoid other parts to be damaged and to grant that the machine will properly work afterwards. Based on experience of reuse and repair centres, when bearings are screwed or when fastened to a metal tub it is easier and

The inclusion of bearings in this list should be further investigated and discussed with stakeholders.

For DWs **[80]**:

- circulation pumps and drain pumps;
- electronics — control electronics, relays, sensors, program selectors, control panels, displays;
- mechanical or electronic aquastop, inlet valves, water distributor;
- doors, door brakes, handles, locks and seals;
- drain hose and inlet hoses;
- water tank, salt container and detergent dispenser;
- pressure control;
- heater;
- spray arms.

Manufacturers could provide documentation on the sequence for the disassembly operations needed to access the above parts. Each of these operations should be described in terms of type of operation, type and number of fastening techniques to be unlocked and tool(s) required. Manufacturers could also provide similar documentation for the reassembly sequence. Gluing or welding fastening techniques should be avoided for these components, unless it is proved that such fastening improves product durability.

In order to improve the reparability of products, it is recommended that manufacturers facilitate the availability of spare parts for the components listed in Box C. For example, manufacturers could provide information in the user manuals and on their own website on how these spare parts can be procured. The use of dedicated platforms (such as the abovementioned Agora system in France) to provide information about the availability of spare parts and their procurement should be also encouraged. Manufacturers could also provide a declaration on how many years these spare parts will be available after the product is put on the market, for example in line with the prescriptions of the French consumption law of 17 March 2014.

However, it is crucial to clearly define what ‘spare parts’ are. This could be part of the standardisation work to be performed within the standardisation mandate M/543[81].

Additional strategies to promote reparability could include:

- the design of products for ease of disassembly[82], to be assessed by metrics specifically developed for this purpose [83];

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economically feasible to replace them (cost around 200€, including labour). In the case of two-pieces plastic tub, it is possible to replace the rear part of the tub including the bearings (with costs very variable, from 300€ to 700€). Otherwise, when the bearings are fastened to a single-piece plastic tub, the repair is generally technically not feasible, while the replacement of the whole ‘washing unit’ (drum, tub, bearing) is generally too expensive.

[80] This list includes components that fail and are repaired most frequently in DW, as discussed in Section 3.3.3.

[81] M/543 Commission Implementing Decision C(2015)9096 of 17.12.2015 on a standardisation request to the European standardisation organisations as regards ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC of the European Parliament and of the Council

- the promotion of labels awarded to products that are designed for easy repair (e.g. the label based on standard ONR 192102:2014).

Recommendations to improve the reusability of WM and DW

Chapter 2 identified the main criticalities concerning product reuse and also possible strategies to overcome them. In addition to previous recommendations to improve reparability, which also facilitate the reuse of the products, potential suggestions to facilitate the design for reuse of WM and DW are listed hereinafter (Box D). These suggestions are based on information and feedback received by reuse centres (as discussed in Section 2.6.3.5).

Box D. Availability of relevant information for the reuse of WM and DW

In order to facilitate the reuse of WM and DW, reuse centres and professional repairers should be provided with the following relevant information:

- the product's exploded diagram with a clear list of referenced parts and information for disassembly (including required tools);
- the list of the test/diagnosis programs applicable to the device and of details of the related error codes (including the suggested actions to be undertaken for each detected failure);
- wiring diagrams and connection diagrams.

Moreover, reuse centres and professional repairers should have access to tools and systems that allow to re-program electronic components and erase error codes in the machines after the repair services.

It is also highlighted that this information is generally available for authorized repair centres, while it is not always the case for independent repairers.

Additional strategies to facilitate the reuse of WM and DW could include:

- the provision of additional guarantees for reused products put on the market by reuse centres;
- the promotion of information campaigns to illustrate the economic, environmental and social benefits of reusing these products and the procedures and standards put in place by reuse centres to guarantee the quality of reused products;
- the promotion of specific markings for the quality of reused products (e.g. the label based on standard PAS 141) and best practices for the preparation for reuse.

It is also crucial that products discarded by users, but still having a certain potential for reuse, are not damaged during the collection phase. Reuse centres would benefit of

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[82] For example, the disassembly and repair operations are is easier for service technicians when all (or most) of the relevant parts can be accessed from one side of the machine.

[83] For examples of metrics to assess ease of disassembly, see: Vanegas, P., Peeters, J. R., Cattrysse, D., Duflou, J. R., Tecchio, P., Mathieux, F. and Ardente, F. (2016), *Study for a method to assess the ease of disassembly of electrical and electronic equipment — Method development and application in a flat panel display case study*, EUR 27921 EN. doi:10.2788/130925 (available at: https://ec.europa.eu/jrc/en/publication/study-method-assess-ease-disassembly-electrical-and-electronic-equipment-method-development-and?search).

having access to discarded products at an early stage of their collection. This access should be facilitated by either collection schemes, municipalities or other operators (such as retailers). In this sense, it is necessary to build cooperation among all the main actors involved. Policies set out in the waste framework directive and the WEEE directive could contribute to this purpose.

Concluding remark

This chapter illustrated a series of recommendations potentially applicable to WM and DW. These were developed and classified according to the three topics addressed in the report: durability, reusability and reparability.

However, as these material efficiency topics are intrinsically interconnected, some recommendations and design strategies could be combined in order to address them simultaneously with a single potential requirement. For example, recommendations on reparability (Box C) and reusability (Box D) could be merged to facilitate both aspects. This further study could be addressed during the policy discussion with different stakeholders.

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A. Annex — Supporting information for durability analysis

Table A.1. WM base-case bill of materials (JRC, 2016b)

Mass (g)	**Material category**	**Material type**
17 984	Ferrous metals	Stainless steel
7 898	Ferrous metals	Steel sheet
1 779	Ferrous metals	Cast iron
866	Ferrous metals	Steel
2 347	Non-ferrous metals	Aluminium
1 356	Non-ferrous metals	Copper
379	Non-ferrous metals	Copper wire
2 000	Plastics	PP
1 740	Plastics	ABS
1 468	Plastics	Elastomer EPDM
95	Plastics	PVC (wire)
22	Plastics	PET
15	Plastics	PE foil
6 138	Plastics	Glass fibre filler
126	Plastics	POM
121	Plastics	Talc
46	Plastics	PMMA
24	Plastics	PA
1	Plastics	PUR
225	Electronics	Circuit board
20 186	Other materials	Concrete
1 870	Other materials	Glass
66 686	**Total mass (packaging excluded)**	
2 000	Packaging	Wood
510	Packaging	EPS
210	Packaging	Cardboard
130	Packaging	PE
66	Packaging	Paper
69 602	**Total mass**	

Table A.2. DW base-case bill of materials (JRC, 2016a)

Mass (g)	**Material category**	**Material type**
5 400.4	Other	Bitumen
884.2	Plastic	ABS — acrylonitrile butadiene styrene
3 712	Ferrous metals	Galvanised steel sheet
2 240	Other	Chipboard
3 166.4	Ferrous metals	Stainless steel coil
0.9	Other	Tape
6 464.8	Ferrous metals	Stainless steel coil
18.8	Ferrous metals	Stainless steel coil
67.7	Non-ferrous metals	Copper
8.8	Non-ferrous metals	Zinc alloy
0.1	Other	Tape
395.6	Plastic	EPDM — ethylene propylene diene monomer rubber
4.3	Plastic	EPS — expanded polystyrene
129.1	Ferrous metals	Galvanised steel
2 933.9	Ferrous metals	Galvanised steel
4 921.3	Ferrous metals	Galvanised steel
131.7	Plastic	PA6 — polyamide 6
14	Plastic	PC — polycarbonate
216.5	Plastic	PC+ABS
136.4	Plastic	HDPE — high-density polyethylene
69	Plastic	PMMA — poly(methyl methacrylate)
366.7	Plastic	POM — polyoxymethylene (as formaldehyde)
6 523	Plastic	PP — polypropylene
15.3	Plastic	PP — polypropylene
3.8	Plastic	Glass fibre[84]
104.4	Plastic	PP — polypropylene
44.8	Plastic	Glass fibre
370	Plastic	PUR — polyurethane flexible foam
6.8	Plastic	PUR rigid — polyurethane rigid foam
389.5	Plastic	PVC — polyvinylchloride
498.8	Other	Rating plate — paper
10.9	Plastic	Silicone (modelled as SBR — styrene-butadiene rubber)
207.3	Ferrous metals	Steel tube
24	Plastic	TPE — thermoplastic elastomers (modelled as SBR)
1 162.4	Plastic	PET — polyethylene terephthalate
5 180	Non-ferrous metals	Zinc
1 381.5	Electronics	Electronics
574.7	Non-ferrous metals	Copper
47 780.08	**Total mass (packaging excluded)**	

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[84] Included in the category 'Plastic' as used in PP.

Mass (g)	**Material category**	**Material type**
407	Packaging	Cardboard
787.92	Packaging	EPS — expanded polystyrene
138	Packaging	LDPE — low-density polyethylene
49 112.72	**Total mass**	

Table A.3. Ecoinvent process: printed wiring board production, surface mounted, unspecified, Pb free

Output	**Amount**	**Unit**
printed wiring board, surface mounted, unspecified, Pb free	1	kg
Input		
capacitor, for surface-mounting	0.033	kg
diode, glass-, for surface-mounting	0.004	kg
electric connector, peripheral component interconnect buss	0.019	kg
integrated circuit, logic type	0.173	kg
light emitting diode	0.001	kg
resistor, surface-mounted	0.023	kg
transistor, surface-mounted	0.010	kg
mounting, surface mount technology, Pb-free solder	0.232	m2
printed wiring board, for surface mounting, Pb free surface	0.232	m2

Table A.4. Aggregate midpoint results for a compact powder laundry detergent — reference flow: 81.5 g (Golsteijn et al., 2015)

Impact category	Unit	Ingredients	Formulation	Packaging	Transport	End of life
Climate change	kg CO_2 eq.	0.127	1.77E-02	7.58E-03	1.61E-02	2.08E-02
Ozone depletion	kg CFC-11 eq.	1.67E-08	8.70E-10	7.07E-10	2.59E-09	8.13E-10
Terrestrial acidification	kg SO2 eq.	5.69E-04	7.37E-05	2.16E-05	9.32E-05	4.79E-05
Freshwater eutrophication	kg P eq.	1.20E-04	1.75E-05	2.35E-06	1.55E-06	3.80E-06
Marine eutrophication	kg N eq.	1.63E-04	4.97E-06	6.73E-06	5.55E-06	4.11E-06
Photochemical oxidant formation	kg NMVOC	3.85E-04	3.70E-05	2.30E-05	1.57E-04	5.86E-05
Particulate matter formation	kg PM10 eq.	2.09E-04	2.33E-05	7.63E-06	4.12E-05	3.28E-05
Ionising radiation	kg U235 eq.	4.25E-02	1.39E-02	8.75E-04	1.47E-03	3.51E-03
Agricultural land occupation	m2a	3.53E-02	2.29E-04	3.50E-03	6.59E-05	1.87E-04
Urban land occupation	m2a	1.05E-03	5.57E-05	8.22E-05	1.75E-04	3.96E-04
Natural land transformation	m2	2.91E-04	1.88E-06	1.91E-06	5.84E-06	9.64E-08
Water depletion	m3	2.76E-03	1.44E-04	7.19E-05	6.43E-05	4.66E-04
Metal depletion	kg Fe eq.	1.02E-02	2.10E-04	3.12E-04	8.41E-04	5.73E-03
Fossil depletion	kg oil eq.	4.27E-02	4.81E-03	2.62E-03	5.75E-03	4.15E-03

Table A.5. Aggregate midpoint results for a compact dishwasher detergent — reference flow: 20 g (Arendorf et al., 2014)

Impact category	**Unit**	**Ingredients**	**Formulation**	**Packaging**	**Transport**	**End of life**
Climate change	kg CO_2 eq.	4.55E-02	1.77E-02	4.56E-03	9.75E-03	8.44E-03
Ozone depletion	kg CFC-11 eq.	5.28E-09	8.70E-10	3.60E-10	1.56E-09	4.55E-10
Terrestrial acidification	kg SO2 eq.	2.12E-04	7.37E-05	1.30E-05	5.90E-05	1.78E-05
Freshwater eutrophication	kg P eq.	1.81E-05	1.75E-05	1.22E-06	9.54E-07	4.74E-06
Marine eutrophication	kg N eq.	5.03E-05	4.97E-06	3.48E-06	3.40E-06	2.77E-06
Photochemical oxidant formation	kg NMVOC	9.43E-05	3.70E-05	1.44E-05	9.63E-05	1.85E-05
Particulate matter formation	kg PM10 eq.	6.05E-05	2.33E-05	4.56E-06	2.56E-05	1.12E-05
Ionising radiation	kg U235 eq.	1.30E-02	1.39E-02	4.45E-04	8.97E-04	4.41E-03
Agricultural land occupation	m2a	3.31E-03	2.29E-04	1.78E-03	3.98E-05	3.11E-04
Urban land occupation	m2a	1.64E-04	5.57E-05	4.19E-05	1.05E-04	1.25E-04
Natural land transformation	m2	1.98E-05	1.88E-06	9.71E-07	3.56E-06	1.08E-07
Water depletion	m3	1.07E-03	1.44E-04	3.82E-05	3.88E-05	2.85E-04
Metal depletion	kg Fe eq.	2.36E-03	2.10E-04	1.59E-04	5.05E-04	1.72E-03
Fossil depletion	kg oil eq.	1.40E-02	4.81E-03	1.89E-03	3.49E-03	2.31E-03

B. Annex — Environmental assessment of the reuse of case-study products for different reuse durations

Environmental assessment of the reuse of a WM (situation 2)

Table B.1. WM reuse (situation 2): with the length of reuse of 4 and 6 years

	φ (performance after refurbishment)			**φ** (performance after refurbishment)		
	upgraded	constant	downgraded	upgraded	constant	downgraded
	95 %	100 %	105 %	95 %	100 %	105 %
	x (years)			**x (years)**		
	4			**6**		
Acidification (mole of H+ eq.)	15.5 %	14.7 %	13.9 %	23.5 %	22.3 %	21.1 %
Climate change (GWP) (kg CO_2 equiv.)	5.7 %	4.9 %	4.1 %	8.8 %	7.5 %	6.3 %
Ecotoxicity freshwater (CTUe)	29.1 %	29.0 %	28.9 %	43.8 %	43.7 %	43.6 %
Eutrophication freshwater (kg P eq.)	0 %	0 %	0 %	0.1 %	0.1 %	0.1 %
Eutrophication marine (kg N equiv.)	1.4 %	1.3 %	1.1 %	2.2 %	1.9 %	1.7 %
Eutrophication terrestrial (mole of N eq.)	13.1 %	12.2 %	11.4 %	20.1 %	18.8 %	17.5 %
Human toxicity, cancer effects (CTUh)	25.8 %	25.7 %	25.5 %	39.0 %	38.7 %	38.4 %
Human toxicity, non-cancer effects (CTUh)	25.1 %	24.8 %	24.5 %	37.8 %	37.3 %	36.9 %
Ionising radiation, human health (kBq U235 eq.)	2.8 %	1.3 %	– 0.2 %	4.4 %	2.1 %	– 0.2 %
Ozone depletion (kg CFC-11 eq.)	2.2 %	2.2 %	2.2 %	3.4 %	3.4 %	3.3 %
Particulate matter (kg PM2.5 equiv.)	18.5 %	17.8 %	17.2 %	27.9 %	26.9 %	26.0 %
Photochemical ozone formation (kg NMVOC)	8.3 %	7.7 %	7.2 %	12.6 %	11.8 %	11.1 %
Resource depletion water (m^3 eq.)	1.1 %	0.7 %	0.3 %	1.7 %	1.1 %	0.6 %
Abiotic depletion (ADP fossil) (MJ)	5.1 %	4.5 %	3.8 %	7.8 %	6.9 %	5.9 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	31.4 %	31.4 %	31.4 %	47.2 %	47.2 %	47.2 %

Table B.2. WM reuse (situation 2): with the length of reuse of 8 and 10 years

	φ (performance after refurbishment)			**φ** (performance after refurbishment)		
	upgraded	constant	downgraded	upgraded	constant	downgraded
	95 %	100 %	105 %	95 %	100 %	105 %
	x (years)			**x (years)**		
	8			**10**		
Acidification (mole of H+ eq.)	31.5 %	29.9 %	28.3 %	39.5 %	37.5 %	35.5 %
Climate change (GWP) (kg CO_2 equiv.)	11.8 %	10.1 %	8.5 %	14.8 %	12.7 %	10.7 %
Ecotoxicity freshwater (CTUe)	58.6 %	58.4 %	58.2 %	73.3 %	73.1 %	72.9 %
Eutrophication freshwater (kg P eq.)	0.2 %	0.1 %	0.1 %	0.2 %	0.2 %	0.2 %
Eutrophication marine (kg N equiv.)	2.9 %	2.6 %	2.3 %	3.7 %	3.3 %	2.9 %
Eutrophication terrestrial (mole of N eq.)	27.1 %	25.3 %	23.6 %	34.1 %	31.9 %	29.7 %
Human toxicity, cancer effects (CTUh)	52.1 %	51.7 %	51.3 %	65.2 %	64.7 %	64.2 %
Human toxicity, non-cancer effects (CTUh)	50.4 %	49.9 %	49.3 %	63.1 %	62.4 %	61.7 %
Ionising radiation, human health (kBq U235 eq.)	5.9 %	2.9 %	– 0.2 %	7.4 %	3.6 %	– 0.2 %
Ozone depletion (kg CFC-11 eq.)	4.5 %	4.5 %	4.5 %	5.7 %	5.6 %	5.6 %
Particulate matter (kg PM2.5 equiv.)	37.4 %	36.1 %	34.8 %	46.8 %	45.2 %	43.6 %
Photochemical ozone formation (kg NMVOC)	17.0 %	16.0 %	14.9 %	21.4 %	20.1 %	18.8 %
Resource depletion water (m^3 eq.)	2.3 %	1.6 %	0.8 %	2.9 %	2.0 %	1.1 %
Abiotic depletion (ADP fossil) (MJ)	10.5 %	9.3 %	8.0 %	13.3 %	11.7 %	10.1 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	63.1 %	63.1 %	63.0 %	78.9 %	78.9 %	78.9 %

Environmental assessment of the reuse of a WM (situation 3)

Table B.3. WM reuse (situation 3): assessment for different impact categories under different initial assumptions

x 4 years	**Acidification midpoint (Mole H+ eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	16 %	15 %	14 %
95 %	15 %	14 %	13 %
90 %	14 %	13 %	12 %
85 %	13 %	12 %	12 %
80 %	12 %	12 %	11 %
75 %	12 %	11 %	10 %
70 %	11 %	10 %	9 %

x 6 years	**Acidification midpoint (Mole H+ eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	24 %	22 %	21 %
95 %	22 %	21 %	20 %
90 %	21 %	20 %	19 %
85 %	20 %	19 %	18 %
80 %	19 %	18 %	16 %
75 %	18 %	16 %	15 %
70 %	16 %	15 %	14 %

x 8 years	**Acidification midpoint (Mole H+ eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	32 %	30 %	28 %
95 %	30 %	28 %	27 %
90 %	28 %	27 %	25 %
85 %	27 %	25 %	23 %
80 %	25 %	23 %	22 %
75 %	23 %	22 %	20 %
70 %	22 %	20 %	19 %

x 10 years	**Acidification midpoint (Mole H+ eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	39 %	37 %	35 %
95 %	37 %	35 %	33 %
90 %	35 %	33 %	31 %
85 %	33 %	31 %	29 %
80 %	31 %	29 %	27 %
75 %	29 %	27 %	25 %
70 %	27 %	25 %	23 %

x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	6%	5%	4%
95 %	5%	4%	3%
90 %	4%	3%	2%
85 %	3%	2%	2%
80 %	2%	2%	1%
75 %	2%	1%	0%
70 %	1%	0%	-1%

x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	12%	10%	8%
95 %	10%	8%	7%
90 %	8%	7%	5%
85 %	7%	5%	3%
80 %	5%	3%	2%
75 %	3%	2%	0%
70 %	2%	0%	-2%

x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	9%	8%	6%
95 %	8%	6%	5%
90 %	6%	5%	4%
85 %	5%	4%	3%
80 %	4%	3%	1%
75 %	3%	1%	0%
70 %	1%	0%	-1%

x	**Climate change (excl. bio.) (kg CO_2 eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	15%	13%	11%
95 %	13%	11%	9%
90 %	11%	9%	6%
85 %	9%	6%	4%
80 %	6%	4%	2%
75 %	4%	2%	0%
70 %	2%	0%	-2%

x	**Ecotoxicity freshwater (CTUe)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	29 %	29 %	29 %
95 %	29 %	29 %	29 %
90 %	29 %	29 %	29 %
85 %	29 %	29 %	29 %
80 %	29 %	29 %	29 %
75 %	29 %	29 %	28 %
70 %	29 %	28 %	28 %

x	**Ecotoxicity freshwater (CTUe)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	44 %	44 %	44 %
95 %	44 %	44 %	43 %
90 %	44 %	43 %	43 %
85 %	43 %	43 %	43 %
80 %	43 %	43 %	43 %
75 %	43 %	43 %	43 %
70 %	43 %	43 %	43 %

x	**Ecotoxicity freshwater (CTUe)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	59 %	58 %	58 %
95 %	58 %	58 %	58 %
90 %	58 %	58 %	58 %
85 %	58 %	58 %	58 %
80 %	58 %	58 %	58 %
75 %	58 %	58 %	57 %
70 %	58 %	57 %	57 %

x	**Ecotoxicity freshwater (CTUe)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	73 %	73 %	73 %
95 %	73 %	73 %	73 %
90 %	73 %	73 %	72 %
85 %	73 %	72 %	72 %
80 %	72 %	72 %	72 %
75 %	72 %	72 %	72 %
70 %	72 %	72 %	72 %

x	**Eutrophication freshwater (kg P eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x	**Eutrophication freshwater (kg P eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x	**Eutrophication freshwater (kg P eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x	**Eutrophication freshwater (kg P eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x 4 years	Eutrophication marine (kg N-eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	1 %	1 %	1 %
95 %	1 %	1 %	1 %
90 %	1 %	1 %	1 %
85 %	1 %	1 %	1 %
80 %	1 %	1 %	0 %
75 %	1 %	0 %	0 %
70 %	0 %	0 %	0 %

x 8 years	Eutrophication marine (kg N-eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	3 %	3 %	2 %
95 %	3 %	2 %	2 %
90 %	2 %	2 %	2 %
85 %	2 %	2 %	1 %
80 %	2 %	1 %	1 %
75 %	1 %	1 %	1 %
70 %	1 %	1 %	0 %

x 6 years	Eutrophication marine (kg N-eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	2 %	2 %	2 %
95 %	2 %	2 %	1 %
90 %	2 %	1 %	1 %
85 %	1 %	1 %	1 %
80 %	1 %	1 %	1 %
75 %	1 %	1 %	1 %
70 %	1 %	1 %	0 %

x 10 years	Eutrophication marine (kg N-eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	4 %	3 %	3 %
95 %	3 %	3 %	3 %
90 %	3 %	3 %	2 %
85 %	3 %	2 %	2 %
80 %	2 %	2 %	1 %
75 %	2 %	1 %	1 %
70 %	1 %	1 %	1 %

x	**Eutrophication terrestrial (mole of N eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	13 %	12 %	11 %
95 %	12 %	11 %	10 %
90 %	11 %	10 %	10 %
85 %	10 %	10 %	9 %
80 %	10 %	9 %	8 %
75 %	9 %	8 %	7 %
70 %	8 %	7 %	6 %

x	**Eutrophication terrestrial (mole of N eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	20 %	19 %	17 %
95 %	19 %	17 %	16 %
90 %	17 %	16 %	15 %
85 %	16 %	15 %	13 %
80 %	15 %	13 %	12 %
75 %	13 %	12 %	11 %
70 %	12 %	11 %	10 %

x	**Eutrophication terrestrial (mole of N eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	27 %	25 %	24 %
95 %	25 %	24 %	22 %
90 %	24 %	22 %	20 %
85 %	22 %	20 %	18 %
80 %	20 %	18 %	17 %
75 %	18 %	17 %	15 %
70 %	17 %	15 %	13 %

x	**Eutrophication terrestrial (mole of N eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	34 %	32 %	30 %
95 %	32 %	30 %	27 %
90 %	30 %	27 %	25 %
85 %	27 %	25 %	23 %
80 %	25 %	23 %	21 %
75 %	23 %	21 %	19 %
70 %	21 %	19 %	16 %

x	**Human toxicity cancer (CTUh)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	26 %	26 %	25 %
95 %	26 %	25 %	25 %
90 %	25 %	25 %	25 %
85 %	25 %	25 %	25 %
80 %	25 %	25 %	25 %
75 %	25 %	25 %	25 %
70 %	25 %	25 %	24 %

x	**Human toxicity cancer (CTUh)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	39 %	39 %	38 %
95 %	39 %	38 %	38 %
90 %	38 %	38 %	38 %
85 %	38 %	38 %	38 %
80 %	38 %	38 %	37 %
75 %	38 %	37 %	37 %
70 %	37 %	37 %	37 %

x	**Human toxicity cancer (CTUh)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	52 %	52 %	51 %
95 %	52 %	51 %	51 %
90 %	51 %	51 %	51 %
85 %	51 %	51 %	50 %
80 %	51 %	50 %	50 %
75 %	50 %	50 %	49 %
70 %	50 %	49 %	49 %

x	**Human toxicity cancer (CTUh)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	65 %	65 %	64 %
95 %	65 %	64 %	64 %
90 %	64 %	64 %	63 %
85 %	64 %	63 %	63 %
80 %	63 %	63 %	62 %
75 %	63 %	62 %	62 %
70 %	62 %	62 %	61 %

x 4 years	**Human toxicity, non-cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	25 %	25 %	25 %
95 %	25 %	25 %	24 %
90 %	25 %	24 %	24 %
85 %	24 %	24 %	24 %
80 %	24 %	24 %	23 %
75 %	24 %	23 %	23 %
70 %	23 %	23 %	23 %

x 6 years	**Human toxicity, non-cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	38 %	37 %	37 %
95 %	37 %	37 %	37 %
90 %	37 %	37 %	36 %
85 %	37 %	36 %	36 %
80 %	36 %	36 %	35 %
75 %	36 %	35 %	35 %
70 %	35 %	35 %	34 %

x 8 years	**Human toxicity, non-cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	50 %	50 %	49 %
95 %	50 %	49 %	49 %
90 %	49 %	49 %	48 %
85 %	49 %	48 %	48 %
80 %	48 %	48 %	47 %
75 %	48 %	47 %	47 %
70 %	47 %	47 %	46 %

x 10 years	**Human toxicity, non-cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	63 %	62 %	62 %
95 %	62 %	62 %	61 %
90 %	62 %	61 %	60 %
85 %	61 %	60 %	60 %
80 %	60 %	60 %	59 %
75 %	60 %	59 %	58 %
70 %	59 %	58 %	58 %

x 4 years	**Ionising radiation (kBq U235 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	3 %	1 %	0 %
95 %	1 %	0 %	– 2 %
90 %	0 %	– 2 %	– 3 %
85 %	– 2 %	– 3 %	– 5 %
80 %	– 3 %	– 5 %	– 6 %
75 %	– 5 %	– 6 %	– 8 %
70 %	– 6 %	– 8 %	– 9 %

x 6 years	**Ionising radiation (kBq U235 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	4%	2%	0%
95 %	2%	0%	-2%
90 %	0%	-2%	-5%
85 %	-2%	-5%	-7%
80 %	-5%	-7%	-9%
75 %	-7%	-9%	-12%
70 %	-9%	-12%	-14%

x 8 years	**Ionising radiation (kBq U235 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	6%	3%	0%
95 %	3%	0%	-3%
90 %	0%	-3%	-6%
85 %	-3%	-6%	-9%
80 %	-6%	-9%	-12%
75 %	-9%	-12%	-15%
70 %	-12%	-15%	-18%

x 10 years	**Ionising radiation (kBq U235 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	7%	4%	0%
95 %	4%	0%	-4%
90 %	0%	-4%	-8%
85 %	-4%	-8%	-12%
80 %	-8%	-12%	-15%
75 %	-12%	-15%	-19%
70 %	-15%	-19%	-23%

x 4 years	**Ozone depletion (kg CFC-11 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	2 %	2 %	2 %
95 %	2 %	2 %	2 %
90 %	2 %	2 %	2 %
85 %	2 %	2 %	2 %
80 %	2 %	2 %	2 %
75 %	2 %	2 %	2 %
70 %	2 %	2 %	2 %

x 6 years	**Ozone depletion (kg CFC-11 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	3 %	3 %	3 %
95 %	3 %	3 %	3 %
90 %	3 %	3 %	3 %
85 %	3 %	3 %	3 %
80 %	3 %	3 %	3 %
75 %	3 %	3 %	3 %
70 %	3 %	3 %	3 %

x 8 years	**Ozone depletion (kg CFC-11 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	5 %	4 %	4 %
95 %	4 %	4 %	4 %
90 %	4 %	4 %	4 %
85 %	4 %	4 %	4 %
80 %	4 %	4 %	4 %
75 %	4 %	4 %	4 %
70 %	4 %	4 %	4 %

x 10 years	**Ozone depletion (kg CFC-11 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	6%	6%	6%
95 %	6%	6%	6%
90 %	6%	6%	6%
85 %	6%	6%	5%
80 %	6%	5%	5%
75 %	5%	5%	5%
70 %	5%	5%	5%

x 4 years	**Particulate matter (kg PM2.5 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	18 %	18 %	17 %
95 %	18 %	17 %	17 %
90 %	17 %	17 %	16 %
85 %	17 %	16 %	15 %
80 %	16 %	15 %	15 %
75 %	15 %	15 %	14 %
70 %	15 %	14 %	13 %

x 8 years	**Particulate matter (kg PM2.5 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	37 %	36 %	35 %
95 %	36 %	35 %	33 %
90 %	35 %	33 %	32 %
85 %	33 %	32 %	31 %
80 %	32 %	31 %	30 %
75 %	31 %	30 %	28 %
70 %	30 %	28 %	27 %

x 6 years	**Particulate matter (kg PM2.5 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	28 %	27 %	26 %
95 %	27 %	26 %	25 %
90 %	26 %	25 %	24 %
85 %	25 %	24 %	23 %
80 %	24 %	23 %	22 %
75 %	23 %	22 %	21 %
70 %	22 %	21 %	20 %

x 10 years	**Particulate matter (kg PM2.5 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	47 %	45 %	44 %
95 %	45 %	44 %	42 %
90 %	44 %	42 %	40 %
85 %	42 %	40 %	39 %
80 %	40 %	39 %	37 %
75 %	39 %	37 %	35 %
70 %	37 %	35 %	34 %

x	Photochemical ozone formation (kg NMVOC)		
4 years	φ		
δ	95 %	100 %	105 %
100 %	8 %	8 %	7 %
95 %	8 %	7 %	7 %
90 %	7 %	7 %	6 %
85 %	7 %	6 %	6 %
80 %	6 %	6 %	5 %
75 %	6 %	5 %	5 %
70 %	5 %	5 %	4 %

x	Photochemical ozone formation (kg NMVOC)		
8 years	φ		
δ	95 %	100 %	105 %
100 %	17 %	16 %	15 %
95 %	16 %	15 %	14 %
90 %	15 %	14 %	13 %
85 %	14 %	13 %	12 %
80 %	13 %	12 %	11 %
75 %	12 %	11 %	10 %
70 %	11 %	10 %	9 %

x	Photochemical ozone formation (kg NMVOC)		
6 years	φ		
δ	95 %	100 %	105 %
100 %	13 %	12 %	11 %
95 %	12 %	11 %	10 %
90 %	11 %	10 %	9 %
85 %	10 %	9 %	9 %
80 %	9 %	9 %	8 %
75 %	9 %	8 %	7 %
70 %	8 %	7 %	6 %

x	Photochemical ozone formation (kg NMVOC)		
10 years	φ		
δ	95 %	100 %	105 %
100 %	21 %	20 %	19 %
95 %	20 %	19 %	17 %
90 %	19 %	17 %	16 %
85 %	17 %	16 %	15 %
80 %	16 %	15 %	14 %
75 %	15 %	14 %	12 %
70 %	14 %	12 %	11 %

x 4 years	Resource depletion water (m³ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	1 %	1 %	0 %
95 %	1 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	– 1 %
80 %	0 %	– 1 %	– 1 %
75 %	– 1 %	– 1 %	– 2 %
70 %	– 1 %	– 2 %	– 2 %

x 6 years	Resource depletion water (m³ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	2 %	1 %	1 %
95 %	1 %	1 %	0 %
90 %	1 %	0 %	– 1 %
85 %	0 %	– 1 %	– 1 %
80 %	– 1 %	– 1 %	– 2 %
75 %	– 1 %	– 2 %	– 2 %
70 %	– 2 %	– 2 %	– 3 %

x 8 years	Resource depletion water (m³ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	2 %	2 %	1 %
95 %	2 %	1 %	0 %
90 %	1 %	0 %	– 1 %
85 %	0 %	– 1 %	– 1 %
80 %	– 1 %	– 1 %	– 2 %
75 %	– 1 %	– 2 %	– 3 %
70 %	– 2 %	– 3 %	– 4 %

x 10 years	Resource depletion water (m³ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	3 %	2 %	1 %
95 %	2 %	1 %	0 %
90 %	1 %	0 %	– 1 %
85 %	0 %	– 1 %	– 2 %
80 %	– 1 %	– 2 %	– 3 %
75 %	– 2 %	– 3 %	– 4 %
70 %	– 3 %	– 4 %	– 4 %

x 4 years	Abiotic depletion (fossil) (MJ)		
	φ		
δ	95 %	100 %	105 %
100 %	5 %	4 %	4 %
95 %	4 %	4 %	3 %
90 %	4 %	3 %	3 %
85 %	3 %	3 %	2 %
80 %	3 %	2 %	1 %
75 %	2 %	1 %	1 %
70 %	1 %	1 %	0 %

x 6 years	Abiotic depletion (fossil) (MJ)		
	φ		
δ	95 %	100 %	105 %
100 %	8 %	7 %	6 %
95 %	7 %	6 %	5 %
90 %	6 %	5 %	4 %
85 %	5 %	4 %	3 %
80 %	4 %	3 %	2 %
75 %	3 %	2 %	1 %
70 %	2 %	1 %	0 %

x 8 years	Abiotic depletion (fossil) (MJ)		
	φ		
δ	95 %	100 %	105 %
100 %	11 %	9 %	8 %
95 %	9 %	8 %	7 %
90 %	8 %	7 %	5 %
85 %	7 %	5 %	4 %
80 %	5 %	4 %	3 %
75 %	4 %	3 %	2 %
70 %	3 %	2 %	0 %

x 10 years	Abiotic depletion (fossil) (MJ)		
	φ		
δ	95 %	100 %	105 %
100 %	13 %	12 %	10 %
95 %	12 %	10 %	8 %
90 %	10 %	8 %	7 %
85 %	8 %	7 %	5 %
80 %	7 %	5 %	4 %
75 %	5 %	4 %	2 %
70 %	4 %	2 %	0 %

x	**Abiotic depletion (elements) (kg Sb equiv.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	31 %	31 %	31 %
95 %	31 %	31 %	31 %
90 %	31 %	31 %	31 %
85 %	31 %	31 %	31 %
80 %	31 %	31 %	31 %
75 %	31 %	31 %	31 %
70 %	31 %	31 %	31 %

x	**Abiotic depletion (elements) (kg Sb equiv.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	47 %	47 %	47 %
95 %	47 %	47 %	47 %
90 %	47 %	47 %	47 %
85 %	47 %	47 %	47 %
80 %	47 %	47 %	47 %
75 %	47 %	47 %	47 %
70 %	47 %	47 %	47 %

x	**Abiotic depletion (elements) (kg Sb equiv.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	63 %	63 %	63 %
95 %	63 %	63 %	63 %
90 %	63 %	63 %	63 %
85 %	63 %	63 %	63 %
80 %	63 %	63 %	63 %
75 %	63 %	63 %	63 %
70 %	63 %	63 %	63 %

x	**Abiotic depletion (elements) (kg Sb equiv.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	79 %	79 %	79 %
95 %	79 %	79 %	79 %
90 %	79 %	79 %	79 %
85 %	79 %	79 %	79 %
80 %	79 %	79 %	79 %
75 %	79 %	79 %	79 %
70 %	79 %	79 %	79 %

Environmental assessment of the reuse of a DW (situation 2)

Table B.4. DW reuse (situation 2): with length of reuse of 4 and 6 years

	φ (performance after refurbishment)			φ (performance after refurbishment)		
	upgraded	constant	downgraded	upgraded	constant	downgraded
	95 %	100 %	105 %	95 %	100 %	105 %
	x (years)			**x (years)**		
	4			**6**		
Acidification (mole of H+ eq.)	10.4 %	9.4 %	8.3 %	16.0 %	14.4 %	12.8 %
Climate change (GWP) (kg CO_2 equiv.)	5.0 %	3.8 %	2.7 %	7.7 %	6.0 %	4.2 %
Ecotoxicity freshwater (CTUe)	26.0 %	25.9 %	25.8 %	40.6 %	40.4 %	40.2 %
Eutrophication freshwater (kg P eq.)	0.2 %	0.1 %	0.1 %	0.4 %	0.3 %	0.2 %
Eutrophication marine (kg N equiv.)	2.1 %	1.7 %	1.2 %	3.3 %	2.6 %	1.9 %
Eutrophication terrestrial (mole of N eq.)	8.7 %	7.5 %	6.4 %	13.4 %	11.7 %	10.0 %
Human toxicity, cancer effects (CTUh)	24.0 %	23.7 %	23.4 %	36.7 %	36.2 %	35.8 %
Human toxicity, non-cancer effects (CTUh)	20.5 %	20.0 %	19.5 %	31.4 %	30.6 %	29.9 %
Ionising radiation, human health (kBq U235 eq.)	2.2 %	0.6 %	– 0.9 %	3.4 %	1.0 %	– 1.3 %
Ozone depletion (kg CFC-11 eq.)	2.5 %	2.4 %	2.4 %	3.8 %	3.7 %	3.6 %
Particulate matter (kg PM2.5 equiv.)	13.2 %	12.2 %	11.3 %	20.2 %	18.9 %	17.5 %
Photochemical ozone formation (kg NMVOC)	7.5 %	6.6 %	5.7 %	11.6 %	10.2 %	8.9 %
Resource depletion water (m^3 eq.)	2.1 %	1.2 %	0.3 %	3.3 %	1.9 %	0.5 %
Abiotic depletion (ADP fossil) (MJ)	6.0 %	4.9 %	3.8 %	9.2 %	7.6 %	6.0 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	29.8 %	29.7 %	29.7 %	45.2 %	45.2 %	45.2 %

Table B.5. DW reuse (situation 2): with length of reuse of 8 and 10 years

	φ (performance after refurbishment)			**φ** (performance after refurbishment)		
	upgraded	constant	downgraded	upgraded	constant	downgraded
	95 %	100 %	105 %	95 %	100 %	105 %
	x (years)			**x (years)**		
	8			**10**		
Acidification (mole of H+ eq.)	21.5 %	19.4 %	17.2 %	27.1 %	24.4 %	21.7 %
Climate change (GWP) (kg CO_2 equiv.)	10.4 %	8.1 %	5.8 %	13.1 %	10.2 %	7.3 %
Ecotoxicity freshwater (CTUe)	55.3 %	55.0 %	54.7 %	69.9 %	69.6 %	69.2 %
Eutrophication freshwater (kg P eq.)	0.5 %	0.5 %	0.4 %	0.7 %	0.6 %	0.5 %
Eutrophication marine (kg N equiv.)	4.5 %	3.5 %	2.6 %	5.7 %	4.5 %	3.3 %
Eutrophication terrestrial (mole of N eq.)	18.1 %	15.8 %	13.5 %	22.8 %	20.0 %	17.1 %
Human toxicity, cancer effects (CTUh)	49.4 %	48.8 %	48.1 %	62.1 %	61.3 %	60.5 %
Human toxicity, non-cancer effects (CTUh)	42.3 %	41.3 %	40.3 %	53.2 %	51.9 %	50.7 %
Ionising radiation, human health (kBq U235 eq.)	4.5 %	1.4 %	– 1.7 %	5.7 %	1.8 %	– 2.1 %
Ozone depletion (kg CFC-11 eq.)	5.1 %	5.0 %	4.9 %	6.4 %	6.3 %	6.1 %
Particulate matter (kg PM2.5 equiv.)	27.3 %	25.5 %	23.7 %	34.4 %	32.1 %	29.8 %
Photochemical ozone formation (kg NMVOC)	15.6 %	13.8 %	12.0 %	19.7 %	17.4 %	15.2 %
Resource depletion water (m^3 eq.)	4.5 %	2.6 %	0.8 %	5.7 %	3.3 %	1.0 %
Abiotic depletion (ADP fossil) (MJ)	12.4 %	10.3 %	8.1 %	15.7 %	12.9 %	10.2 %
Abiotic depletion (ADP elements) (kg Sb equiv.)	60.7 %	60.7 %	60.6 %	76.2 %	76.1 %	76.1 %

Environmental assessment of the reuse of a DW (situation 3)

Table B.6. DW reuse (situation 3): assessment for different impact categories under different initial assumptions

x 4 years	Acidification midpoint (Mole H+ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	10 %	9 %	8 %
95 %	9 %	8 %	7 %
90 %	8 %	7 %	6 %
85 %	7 %	6 %	5 %
80 %	6 %	5 %	4 %
75 %	5 %	4 %	3 %
70 %	4 %	3 %	2 %

x 6 years	Acidification midpoint (Mole H+ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	16 %	14 %	13 %
95 %	14 %	13 %	11 %
90 %	13 %	11 %	10 %
85 %	11 %	10 %	8 %
80 %	10 %	8 %	6 %
75 %	8 %	6 %	5 %
70 %	6 %	5 %	3 %

x 8 years	Acidification midpoint (Mole H+ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	22 %	19 %	17 %
95 %	19 %	17 %	15 %
90 %	17 %	15 %	13 %
85 %	15 %	13 %	11 %
80 %	13 %	11 %	9 %
75 %	11 %	9 %	6 %
70 %	9 %	6 %	4 %

x 10 years	Acidification midpoint (Mole H+ eq.)		
	φ		
δ	95 %	100 %	105 %
100 %	27 %	24 %	22 %
95 %	24 %	22 %	19 %
90 %	22 %	19 %	16 %
85 %	19 %	16 %	14 %
80 %	16 %	14 %	11 %
75 %	14 %	11 %	8 %
70 %	11 %	8 %	6 %

x	Climate change (excl. bio.) (kg CO_2 eq.)		
4 years	φ		
δ	95 %	100 %	105 %
100 %	5%	4%	3%
95 %	4%	3%	2%
90 %	3%	2%	0%
85 %	2%	0%	-1%
80 %	0%	-1%	-2%
75 %	-1%	-2%	-3%
70 %	-2%	-3%	-4%

x	Climate change (excl. bio.) (kg CO_2 eq.)		
6 years	φ		
δ	95 %	100 %	105 %
100 %	8%	6%	4%
95 %	6%	4%	2%
90 %	4%	2%	1%
85 %	2%	1%	-1%
80 %	1%	-1%	-3%
75 %	-1%	-3%	-5%
70 %	-3%	-5%	-6%

x	Climate change (excl. bio.) (kg CO_2 eq.)		
8 years	φ		
δ	95 %	100 %	105 %
100 %	10%	8%	6%
95 %	8%	6%	3%
90 %	6%	3%	1%
85 %	3%	1%	-1%
80 %	1%	-1%	-4%
75 %	-1%	-4%	-6%
70 %	-4%	-6%	-8%

x	Climate change (excl. bio.) (kg CO_2 eq.)		
10 years	φ		
δ	95 %	100 %	105 %
100 %	13%	10%	7%
95 %	10%	7%	4%
90 %	7%	4%	1%
85 %	4%	1%	-1%
80 %	1%	-1%	-4%
75 %	-1%	-4%	-7%
70 %	-4%	-7%	-10%

x	**Ecotoxicity freshwater (CTUe)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	26 %	26 %	26 %
95 %	26 %	26 %	26 %
90 %	26 %	26 %	25 %
85 %	26 %	25 %	25 %
80 %	25 %	25 %	25 %
75 %	25 %	25 %	25 %
70 %	25 %	25 %	25 %

x	**Ecotoxicity freshwater (CTUe)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	41 %	40 %	40 %
95 %	40 %	40 %	40 %
90 %	40 %	40 %	40 %
85 %	40 %	40 %	40 %
80 %	40 %	40 %	39 %
75 %	40 %	39 %	39 %
70 %	39 %	39 %	39 %

x	**Ecotoxicity freshwater (CTUe)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	55 %	55 %	55 %
95 %	55 %	55 %	54 %
90 %	55 %	54 %	54 %
85 %	54 %	54 %	54 %
80 %	54 %	54 %	54 %
75 %	54 %	54 %	53 %
70 %	54 %	53 %	53 %

x	**Ecotoxicity freshwater (CTUe)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	70 %	70 %	69 %
95 %	70 %	69 %	69 %
90 %	69 %	69 %	69 %
85 %	69 %	69 %	68 %
80 %	69 %	68 %	68 %
75 %	68 %	68 %	68 %
70 %	68 %	68 %	67 %

x 4 years	**Eutrophication freshwater (kg P eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x 6 years	**Eutrophication freshwater (kg P eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	0 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x 8 years	**Eutrophication freshwater (kg P eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	1 %	0 %	0 %
95 %	0 %	0 %	0 %
90 %	0 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x 10 years	**Eutrophication freshwater (kg P eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	1 %	1 %	1 %
95 %	1 %	1 %	0 %
90 %	1 %	0 %	0 %
85 %	0 %	0 %	0 %
80 %	0 %	0 %	0 %
75 %	0 %	0 %	0 %
70 %	0 %	0 %	0 %

x	**Eutrophication marine (kg N-eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	2 %	2 %	1 %
95 %	2 %	1 %	1 %
90 %	1 %	1 %	0 %
85 %	1 %	0 %	0 %
80 %	0 %	0 %	– 1 %
75 %	0 %	– 1 %	– 1 %
70 %	– 1 %	– 1 %	– 2 %
x	**Eutrophication marine (kg N-eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	4 %	4 %	3 %
95 %	4 %	3 %	2 %
90 %	3 %	2 %	1 %
85 %	2 %	1 %	0 %
80 %	1 %	0 %	– 1 %
75 %	0 %	– 1 %	– 2 %
70 %	– 1 %	– 2 %	– 3 %

x	**Eutrophication marine (kg N-eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	3 %	3 %	2 %
95 %	3 %	2 %	1 %
90 %	2 %	1 %	0 %
85 %	1 %	0 %	0 %
80 %	0 %	0 %	– 1 %
75 %	0 %	– 1 %	– 2 %
70 %	– 1 %	– 2 %	– 2 %
x	**Eutrophication marine (kg N-eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	6 %	4 %	3 %
95 %	4 %	3 %	2 %
90 %	3 %	2 %	1 %
85 %	2 %	1 %	0 %
80 %	1 %	0 %	– 1 %
75 %	0 %	– 1 %	– 3 %
70 %	– 1 %	– 3 %	– 4 %

x 4 years	**Eutrophication terrestrial (mole of N eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	9 %	8 %	6 %
95 %	8 %	6 %	5 %
90 %	6 %	5 %	4 %
85 %	5 %	4 %	3 %
80 %	4 %	3 %	2 %
75 %	3 %	2 %	1 %
70 %	2 %	1 %	0 %

x 6 years	**Eutrophication terrestrial (mole of N eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	13 %	12 %	10 %
95 %	12 %	10 %	8 %
90 %	10 %	8 %	7 %
85 %	8 %	7 %	5 %
80 %	7 %	5 %	3 %
75 %	5 %	3 %	1 %
70 %	3 %	1 %	0 %

x 8 years	**Eutrophication terrestrial (mole of N eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	18 %	16 %	14 %
95 %	16 %	14 %	11 %
90 %	14 %	11 %	9 %
85 %	11 %	9 %	7 %
80 %	9 %	7 %	4 %
75 %	7 %	4 %	2 %
70 %	4 %	2 %	0 %

x 10 years	**Eutrophication terrestrial (mole of N eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	23 %	20 %	17 %
95 %	20 %	17 %	14 %
90 %	17 %	14 %	11 %
85 %	14 %	11 %	9 %
80 %	11 %	9 %	6 %
75 %	9 %	6 %	3 %
70 %	6 %	3 %	0 %

x 4 years	**Human toxicity cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	24 %	24 %	23 %
95 %	24 %	23 %	23 %
90 %	23 %	23 %	23 %
85 %	23 %	23 %	22 %
80 %	23 %	22 %	22 %
75 %	22 %	22 %	22 %
70 %	22 %	22 %	22 %

x 6 years	**Human toxicity cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	37 %	36 %	36 %
95 %	36 %	36 %	35 %
90 %	36 %	35 %	35 %
85 %	35 %	35 %	34 %
80 %	35 %	34 %	34 %
75 %	34 %	34 %	33 %
70 %	34 %	33 %	33 %

x 8 years	**Human toxicity cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	49 %	49 %	48 %
95 %	49 %	48 %	48 %
90 %	48 %	48 %	47 %
85 %	48 %	47 %	46 %
80 %	47 %	46 %	46 %
75 %	46 %	46 %	45 %
70 %	46 %	45 %	44 %

x 10 years	**Human toxicity cancer (CTUh)**		
	φ		
δ	95 %	100 %	105 %
100 %	62 %	61 %	61 %
95 %	61 %	61 %	60 %
90 %	61 %	60 %	59 %
85 %	60 %	59 %	58 %
80 %	59 %	58 %	57 %
75 %	58 %	57 %	57 %
70 %	57 %	57 %	56 %

x	**Human toxicity, non-cancer (CTUh)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	20 %	20 %	19 %
95 %	20 %	19 %	19 %
90 %	19 %	19 %	19 %
85 %	19 %	19 %	18 %
80 %	19 %	18 %	18 %
75 %	18 %	18 %	17 %
70 %	18 %	17 %	17 %

x	**Human toxicity, non-cancer (CTUh)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	31 %	31 %	30 %
95 %	31 %	30 %	29 %
90 %	30 %	29 %	28 %
85 %	29 %	28 %	28 %
80 %	28 %	28 %	27 %
75 %	28 %	27 %	26 %
70 %	27 %	26 %	25 %

x	**Human toxicity, non-cancer (CTUh)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	42 %	41 %	40 %
95 %	41 %	40 %	39 %
90 %	40 %	39 %	38 %
85 %	39 %	38 %	37 %
80 %	38 %	37 %	36 %
75 %	37 %	36 %	35 %
70 %	36 %	35 %	34 %

x	**Human toxicity, non-cancer (CTUh)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	53 %	52 %	51 %
95 %	52 %	51 %	49 %
90 %	51 %	49 %	48 %
85 %	49 %	48 %	47 %
80 %	48 %	47 %	46 %
75 %	47 %	46 %	45 %
70 %	46 %	45 %	43 %

x	**Ionising radiation (kBq U235 eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	2 %	1 %	– 1 %
95 %	1 %	– 1 %	– 2 %
90 %	– 1 %	– 2 %	– 4 %
85 %	– 2 %	– 4 %	– 6 %
80 %	– 4 %	– 6 %	– 7 %
75 %	– 6 %	– 7 %	– 9 %
70 %	– 7 %	– 9 %	– 10 %
x	**Ionising radiation (kBq U235 eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	5 %	1 %	– 2 %
95 %	1 %	– 2 %	– 5 %
90 %	– 2 %	– 5 %	– 8 %
85 %	– 5 %	– 8 %	– 11 %
80 %	– 8 %	– 11 %	– 14 %
75 %	– 11 %	– 14 %	– 17 %
70 %	– 14 %	– 17 %	– 20 %

x	**Ionising radiation (kBq U235 eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	3 %	1 %	– 1 %
95 %	1 %	– 1 %	– 4 %
90 %	– 1 %	– 4 %	– 6 %
85 %	– 4 %	– 6 %	– 8 %
80 %	– 6 %	– 8 %	– 11 %
75 %	– 8 %	– 11 %	– 13 %
70 %	– 11 %	– 13 %	– 15 %
x	**Ionising radiation (kBq U235 eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	6 %	2 %	– 2 %
95 %	2 %	– 2 %	– 6 %
90 %	– 2 %	– 6 %	– 10 %
85 %	– 6 %	– 10 %	– 14 %
80 %	– 10 %	– 14 %	– 18 %
75 %	– 14 %	– 18 %	– 22 %
70 %	– 18 %	– 22 %	– 25 %

x	**Ozone depletion (kg CFC-11 eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	2 %	2 %	2 %
95 %	2 %	2 %	2 %
90 %	2 %	2 %	2 %
85 %	2 %	2 %	2 %
80 %	2 %	2 %	2 %
75 %	2 %	2 %	2 %
70 %	2 %	2 %	2 %

x	**Ozone depletion (kg CFC-11 eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	5 %	5 %	5 %
95 %	5 %	5 %	5 %
90 %	5 %	5 %	5 %
85 %	5 %	5 %	5 %
80 %	5 %	5 %	4 %
75 %	5 %	4 %	4 %
70 %	4 %	4 %	4 %

x	**Ozone depletion (kg CFC-11 eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	4 %	4 %	4 %
95 %	4 %	4 %	4 %
90 %	4 %	4 %	3 %
85 %	4 %	3 %	3 %
80 %	3 %	3 %	3 %
75 %	3 %	3 %	3 %
70 %	3 %	3 %	3 %

x	**Ozone depletion (kg CFC-11 eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	6 %	6 %	6 %
95 %	6 %	6 %	6 %
90 %	6 %	6 %	6 %
85 %	6 %	6 %	6 %
80 %	6 %	6 %	6 %
75 %	6 %	6 %	5 %
70 %	6 %	5 %	5 %

x	**Particulate matter (kg PM2.5 eq.)**		
4 years	φ		
δ	95 %	100 %	105 %
100 %	13 %	12 %	11 %
95 %	12 %	11 %	10 %
90 %	11 %	10 %	10 %
85 %	10 %	10 %	9 %
80 %	10 %	9 %	8 %
75 %	9 %	8 %	7 %
70 %	8 %	7 %	6 %

x	**Particulate matter (kg PM2.5 eq.)**		
6 years	φ		
δ	95 %	100 %	105 %
100 %	20 %	19 %	17 %
95 %	19 %	17 %	16 %
90 %	17 %	16 %	15 %
85 %	16 %	15 %	13 %
80 %	15 %	13 %	12 %
75 %	13 %	12 %	11 %
70 %	12 %	11 %	9 %

x	**Particulate matter (kg PM2.5 eq.)**		
8 years	φ		
δ	95 %	100 %	105 %
100 %	27 %	25 %	24 %
95 %	25 %	24 %	22 %
90 %	24 %	22 %	20 %
85 %	22 %	20 %	18 %
80 %	20 %	18 %	16 %
75 %	18 %	16 %	15 %
70 %	16 %	15 %	13 %

x	**Particulate matter (kg PM2.5 eq.)**		
10 years	φ		
δ	95 %	100 %	105 %
100 %	34 %	32 %	30 %
95 %	32 %	30 %	28 %
90 %	30 %	28 %	25 %
85 %	28 %	25 %	23 %
80 %	25 %	23 %	21 %
75 %	23 %	21 %	18 %
70 %	21 %	18 %	16 %

x 4 years	Photochemical ozone formation (kg NMVOC)		
	φ		
δ	95 %	100 %	105 %
100 %	8 %	7 %	6 %
95 %	7 %	6 %	5 %
90 %	6 %	5 %	4 %
85 %	5 %	4 %	3 %
80 %	4 %	3 %	2 %
75 %	3 %	2 %	1 %
70 %	2 %	1 %	0 %

x 8 years	Photochemical ozone formation (kg NMVOC)		
	φ		
δ	95 %	100 %	105 %
100 %	16 %	14 %	12 %
95 %	14 %	12 %	10 %
90 %	12 %	10 %	8 %
85 %	10 %	8 %	7 %
80 %	8 %	7 %	5 %
75 %	7 %	5 %	3 %
70 %	5 %	3 %	1 %

x 6 years	Photochemical ozone formation (kg NMVOC)		
	φ		
δ	95 %	100 %	105 %
100 %	12 %	10 %	9 %
95 %	10 %	9 %	7 %
90 %	9 %	7 %	6 %
85 %	7 %	6 %	5 %
80 %	6 %	5 %	3 %
75 %	5 %	3 %	2 %
70 %	3 %	2 %	1 %

x 10 years	Photochemical ozone formation (kg NMVOC)		
	φ		
δ	95 %	100 %	105 %
100 %	20 %	17 %	15 %
95 %	17 %	15 %	13 %
90 %	15 %	13 %	11 %
85 %	13 %	11 %	8 %
80 %	11 %	8 %	6 %
75 %	8 %	6 %	4 %
70 %	6 %	4 %	2 %

x 4 years	**Resource depletion water (m^3 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	2 %	1 %	0 %
95 %	1 %	0 %	– 1 %
90 %	0 %	– 1 %	– 2 %
85 %	– 1 %	– 2 %	– 3 %
80 %	– 2 %	– 3 %	– 3 %
75 %	– 3 %	– 3 %	– 4 %
70 %	– 3 %	– 4 %	– 5 %

x 6 years	**Resource depletion water (m^3 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	3 %	2 %	1 %
95 %	2 %	1 %	– 1 %
90 %	1 %	– 1 %	– 2 %
85 %	– 1 %	– 2 %	– 4 %
80 %	– 2 %	– 4 %	– 5 %
75 %	– 4 %	– 5 %	– 6 %
70 %	– 5 %	– 6 %	– 8 %

x 8 years	**Resource depletion water (m^3 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	4 %	3 %	1 %
95 %	3 %	1 %	– 1 %
90 %	1 %	– 1 %	– 3 %
85 %	– 1 %	– 3 %	– 5 %
80 %	– 3 %	– 5 %	– 7 %
75 %	– 5 %	– 7 %	– 9 %
70 %	– 7 %	– 9 %	– 10 %

x 10 years	**Resource depletion water (m^3 eq.)**		
	φ		
δ	95 %	100 %	105 %
100 %	6 %	3 %	1 %
95 %	3 %	1 %	– 1 %
90 %	1 %	– 1 %	– 4 %
85 %	– 1 %	– 4 %	– 6 %
80 %	– 4 %	– 6 %	– 8 %
75 %	– 6 %	– 8 %	– 11 %
70 %	– 8 %	– 11 %	– 13 %

x	Abiotic depletion (fossil) (MJ)		
4 years	φ		
δ	95 %	100 %	105 %
100 %	6 %	5 %	4 %
95 %	5 %	4 %	3 %
90 %	4 %	3 %	2 %
85 %	3 %	2 %	1 %
80 %	2 %	1 %	– 1 %
75 %	1 %	– 1 %	– 2 %
70 %	– 1 %	– 2 %	– 3 %

x	Abiotic depletion (fossil) (MJ)		
6 years	φ		
δ	95 %	100 %	105 %
100 %	9 %	8 %	6 %
95 %	8 %	6 %	4 %
90 %	6 %	4 %	3 %
85 %	4 %	3 %	1 %
80 %	3 %	1 %	– 1 %
75 %	1 %	– 1 %	– 2 %
70 %	– 1 %	– 2 %	– 4 %

x	Abiotic depletion (fossil) (MJ)		
8 years	φ		
δ	95 %	100 %	105 %
100 %	12 %	10 %	8 %
95 %	10 %	8 %	6 %
90 %	8 %	6 %	4 %
85 %	6 %	4 %	2 %
80 %	4 %	2 %	– 1 %
75 %	2 %	– 1 %	– 3 %
70 %	– 1 %	– 3 %	– 5 %

x	Abiotic depletion (fossil) (MJ)		
10 years	φ		
δ	95 %	100 %	105 %
100 %	16 %	13 %	10 %
95 %	13 %	10 %	8 %
90 %	10 %	8 %	5 %
85 %	8 %	5 %	2 %
80 %	5 %	2 %	– 1 %
75 %	2 %	– 1 %	– 3 %
70 %	– 1 %	– 3 %	– 6 %

x 4 years	**Abiotic depletion (elements) (kg Sb equiv.)**		
	φ		
δ	95 %	100 %	105 %
100 %	30 %	30 %	30 %
95 %	30 %	30 %	30 %
90 %	30 %	30 %	30 %
85 %	30 %	30 %	30 %
80 %	30 %	30 %	30 %
75 %	30 %	30 %	30 %
70 %	30 %	30 %	30 %

x 6 years	**Abiotic depletion (elements) (kg Sb equiv.)**		
	φ		
δ	95 %	100 %	105 %
100 %	45 %	45 %	45 %
95 %	45 %	45 %	45 %
90 %	45 %	45 %	45 %
85 %	45 %	45 %	45 %
80 %	45 %	45 %	45 %
75 %	45 %	45 %	45 %
70 %	45 %	45 %	45 %

x 8 years	**Abiotic depletion (elements) (kg Sb equiv.)**		
	φ		
δ	95 %	100 %	105 %
100 %	61 %	61 %	61 %
95 %	61 %	61 %	61 %
90 %	61 %	61 %	61 %
85 %	61 %	61 %	61 %
80 %	61 %	61 %	60 %
75 %	61 %	60 %	60 %
70 %	60 %	60 %	60 %

x 10 years	**Abiotic depletion (elements) (kg Sb equiv.)**		
	φ		
δ	95 %	100 %	105 %
100 %	76 %	76 %	76 %
95 %	76 %	76 %	76 %
90 %	76 %	76 %	76 %
85 %	76 %	76 %	76 %
80 %	76 %	76 %	76 %
75 %	76 %	76 %	76 %
70 %	76 %	76 %	76 %

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