Repairability criteria for energy related products

Study in the BeNeLux context to evaluate the options to extend the product life time

Final Report

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Abbreviations

AEPL	average expected product lifetime
BLDC	Brushless Direct Current
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
DIY	Do-It-Yourself
eDIM	ease of disassembly method/metric
EEA	electrical and electronic appliances
ErP	energy related product
EUEB	European Union Eco-labelling Board
JRC	Joint Research Center
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MOST	Maynard Operation Sequence Technique
NPV	Net Present Value
NTC	heat-sensor
PC	personal computer
PCB	printed circuit board
PUMU	combined power and motor unit
STB	set top box
TV	television
QR	Quick Response
VAT	Value Added Tax
VC	vacuum cleaner
WM	washing machine

Executive summary

The Benelux Directive on the practical application of the circular economy was signed in December 2016 and has provided the legal framework for Belgium, the Netherlands, Luxembourg and the Benelux Secretariat-General to initiate the research presented in this report.

The overall aim of this study is to evaluate and, if possible, quantify the ease of repair for energy-related products (ErPs) considering the economic impact from a consumer perspective. In order to meet this objective, repairability criteria for ErPs are proposed. The developed criteria are in accordance with the ongoing initiative of the CEN-CELEC WG3 working on the standardization of repairability.

The focus of current study is repair and reuse from a consumer perspective. Many manufacturers, however, are considering shifting their business model from selling product to selling services. In the case of product service systems, repairs usually take place in an industrial environment and are called remanufacture. In this case, the developed repairability criteria may still be useful to identify potential improvement opportunities to increase the ease of repair.

Repair activities are conducted in different ways. It can be done by the manufacturer's or retailer's after sales service (in house), it can be done by professional repairs under contract with manufacturers (outsourced), it can be done by a repair company (independent professional repair) or it can be done by the customer (self-repair). Depending on the repair route, different challenges will arise and this must be taken into account when assessing the repairability of products.

In the first task of the present research, a background study has been carried out to identify existing initiatives or standards that already include a number of repairability criteria. The research presented in this report focuses on scoring schemes applied in Europe and publically available information.

Qualitative evaluation methods generally consist of a number of criteria that need to be fulfilled in order to obtain a label, such as Blue Angel, Nordic Label or European eco-label. These existing initiatives aim to evaluate the environmental performance of products. A number of qualitative criteria related to repair were identified such as the provision of disassembly instructions, ease of disassembly, required tools, use of standardized connections and supply of spare parts.

Semi-quantitative evaluation methods assign a weight to each criteria and sum up these weighted criteria which results in a "repairability score" for the product. The iFIXIT score card is such a semi-quantitative method that has been developed to evaluate the ease of repair for ICT products. Another example is the Austrian Technical Rules ONR 192 102:2014 that can be applied to both large household equipment (white goods) and small electric and electronic equipment (brown goods).

Quantitative methods use measurable data to calculate a reusability index or metric. For example, the Ease of Disassembly method (eDIM) calculates the required disassembly and reassembly time, which can also be used to assess the repairability since disassembly and reassembly activities are an important part of the repair process.

In the second task horizontal repairability criteria are proposed. The developed method is a semi-quantitative method. A general framework has been developed that provides a clear and meaningful structure for each repairability criteria according to the criteria type and the related repair step.

In total 24 criteria are proposed and each of them receive a score depending on the selected option. The different options for each criterium are described in detail and, where possible, measurable data is used. Criteria have been defined related to information provision, such as explanation of error codes, disassembly instructions or spare parts references. Other criteria assess the product design for repair, such as ease of disassembly or individual replacement of priority parts. One of the criteria, related to ease of disassembly, is based on the quantitative eDIM evaluation. Finally, there are also criteria that assess the offered repair services of the manufacturer during the use phase of the product. Although the developed criteria focus on the technical feasibility of repair, for some criteria, such as access to spare parts and repair services, the related cost has been taken into account.

Overall the weights for the generic assessment tool are quite evenly distributed, with some more emphasis on product design (38% of total score), compared to information provision (29%) and service provided by the manufacturer during the use phase (34%). Depending on the product type, the weights of the criteria can be adapted.

Some criteria related to the repairability assessment can be dependent of the targeted priority parts. Before the start of the repairability assessment a list of priority parts should be compiled, if not already available for the relevant product group. Priority parts are independent of current difficulties to be replaced or repaired, hence the priority parts should be identified taking the following into account:

- Most frequent failure modes or misuses of products
- Parts that are most likely to be replaced or repaired during the lifetime of a given product group
- Functional criticality

The developed methodology provides a complete set of criteria related to the different aspects of repairability through the whole repair cycle. However, a number of parameters has to be defined at product group level such as:

- Reference value for the disassembly metric (eDIM)
- List of priority part and common failure modes
- Level of detail of provided information
- Length of the required service (depending on average expected product lifetime)
- Relative cost and availability of spare parts
- Size of labels

In a next step, the developed criteria are applied in specific case studies for washing machines and vacuum cleaners. For each case study, first the selected product group is defined and characterized, the assessed product model is briefly described and, finally, the repairability criteria are applied and the selected options are justified. In addition, the potential economic impact for the consumer is quantified.

In all cases the repairability score for a professional repairer is higher than for a consumer, partly because of the limited information that is available for consumers. For the vacuum cleaners, the accessibility of spare parts is also better for professional repairers compared to consumers.

Some challenges have been identified when applying the developed method. These challenges need to be further explored to refine and improve the current proposed repairability criteria.

An important challenges is the identification of priority parts and failure modes. Because all components can fail, a cut off rule needs to be defined. There are different possibilities. The cut-off can be defined as minimum number of parts (e.g. top 5 most likely to fail components) or it could be set to cover a minimum percentage of likely failures (e.g. 75% of failures). Furthermore, within a specific product group an identified priority part may not be relevant to all product models, such as carbon brushes for washing machines. As products are continuously developed, the number and type of priority parts may change over time.

Furthermore, the availability of spare parts from third parties is not straightfoward to take into account. First, manufacturers are not responsible and cannot control further distribution downstream of (original) spare parts. Second, the compatibility and quality of the spare parts are difficult to verify. Another difficulty is to deal with priority parts that are covered by an extended warranty. In the current study these were not treated differently because even if a part is covered by such an extended warranty, typically the replacement will not be completely free of charge.

Another challenge that was faced during the case studies is the distinction between maintenance, repair and upgrade. At the start of the project, the aim was to clearly separate between these different actions as maintenance aims to avoid repair and because upgrading provides a product with a slightly different function or capacity. In practice however maintenance instruction provided to users may also serve for repair (e.g. cleaning of a filter). Also in consumer surveys, filters were often regarded as failure requiring repair while this is considered to be part of regular maintenance by manufacturers.

In general, devices are becoming increasingly complex as they include more electronic components. The fact that there more (electronic) components are integrated in a product increases the likelihood of a failure occurring during the lifetime of the product. In order to achieve increased material efficiency through extended product lifetime with repair, it will not be sufficient to expect more repairable products from manufacturers, also consumers should be aware that less complex products will typically be more robust. The consumer should only choose products with specific features if this is relevant for his intended use.

Additionally, the different stakeholders should work together to define which type of products and which type of failure can be repaired by consumers through self-repair. A number of (simple) failures can be adequately handled by a consumer without any safety issue or unsafe use arising. However, in some cases professional repair is required. In those cases the aim should be to improve the provided service to consumer: increase accessibility, reduce cost and provide temporary product replacement during repair.

A policy tool that could be used is to extend the warranty period. The warranty period could be defined per product group depending on the average expected product lifetime. The lifecycle costing carried out in this study has indeed concluded that an extended warranty is beneficial if a sufficient part of the expected lifetime is covered by the warranty. Additionally, it was observed that companies manage to reduce the number of returned or failed products during the warranty period below 3%. It is expected that a similar target would be applied to the extended warranty period. However, further research should be carried out to investigate the full consequence of such an extended warranty. Even if the extended warranty is free of charge, it is most likely that this could increase the purchase price. Furthermore, in case of low grade products produced at lower cost, companies may more often decide to replace the failed products rather than repair it, which would not contribute to the overall goal of extended product lifetime to increase material efficiency.

Further research is needed to confirm the correlation between the single score obtained with the proposed repairability method and the ease of repair in real life. In the meanwhile, a number of specific items could be selected to better inform consumers. For example the possibility to replace or upgrade priority parts, the ease of disassembly expressed in time with the eDIM metric or the maintenance and repair service offered during the use of the product. In addition, the lifecycle costing demonstrated the importance of a voluntaristic strategy in the context of repair decisions by the consumer. The lifecycle cost per annum decreases considerably when the consumers allows a high number of repairs of a single device. This observation even holds in case the repair involves a high cost. Only in case the device approaches the end of its expected lifetime, the consumer should become reluctant towards the repair of malfunctioning devices.

The broader use of the developed repairability criteria should be further investigated by applying the method to a larger number of products. Another step toward the implementation of the tool would be to ensure the consistent use of the tool and the robustness of the obtained results (replicability of the method). For example, a test panel of a selected stakeholder could apply the developed method in a pilot project. Such a pilot project involving different stakeholders along the supply chain could also be used to develop vertical criteria for specific product groups.

Other steps that could be investigated at a Benelux-level as laboratory within Europe are the ease of access for the consumer to reparability services (and other types of information for the consumer like labeling) and the development of business models to demonstrate that reparability can be an opportunity for companies.

Samenvatting

De Benelux-richtlijn over de praktische toepassing van de circulaire economie werd ondertekend in december 2016 en biedt het wettelijk kader voor België, Nederland, Luxemburg en het Benelux Secretariaat-Generaal om dit onderzoek te initiëren.

Het algemene doel van deze studie is om het gemak van herstel van energiegerelateerde producten (ErPs) te evalueren en, indien mogelijk, te kwantificeren, rekening houdend met de economische impact vanuit het perspectief van de consument. Om aan deze doelstelling te voldoen, worden herstelbaarheidscriteria voor ErPs voorgesteld. De ontwikkelde herstelcriteria in deze studie zijn in overeenstemming met het lopende initiatief van CEN-CELEC WG3 dat aan de standaardisatie van herstelbaarheid van producten werkt.

De huidige studie heeft zich gericht op herstel en hergebruik vanuit het perspectief van de consument of eindgebruiker. Veel fabrikanten overwegen echter hun bedrijfsmodel te verschuiven naar het verkopen van diensten in plaats van producten. Hierbij vinden herstellingen meestal plaats in een industriële omgeving en spreekt men van *remanufacture*. In dit geval kunnen de ontwikkelde herstelcriteria in deze studie nog steeds nuttig zijn om potentiële verbeteringsmogelijkheden te identificeren om het gemak van herstel te vergroten.

Herstelactiviteiten kunnen plaatsvinden bij de na-verkoop dienst van de fabrikant of de retailer, bij een onafhankelijk professioneel herstelbedrijf of bij de consument zelf. Afhankelijk van de herstelroute ontstaan er verschillende uitdagingen en hiermee moet rekening worden gehouden bij het beoordelen van de herstelbaarheid van producten.

In de eerste taak van deze studie is een achtergrondstudie uitgevoerd om bestaande initiatieven of normen te identificeren die reeds herstelcriteria bevatten. Het onderzoek dat in dit rapport wordt gepresenteerd, is gericht op scoresystemen die in Europa worden toegepast.

Kwalitatieve evaluatiemethoden bestaan uit een aantal criteria waaraan moet worden voldaan om een label te verkrijgen. Voorbeelden van zulke evaluatiemethodes zijn Blue Angel, Nordic Label of het Europese eco-label. Deze bestaande initiatieven zijn gericht op het evalueren van de milieuprestatie van producten. Een aantal kwalitatieve criteria met betrekking tot herstel zijn geïdentificeerd, zoals het verstrekken van demontage-instructies, het gemak van demontage, vereiste gereedschappen bij het vervangen van een onderdeel, het gebruik van gestandaardiseerde aansluitingen en de toegang tot reserveonderdelen.

Semi-kwantitatieve evaluatiemethoden kennen een gewicht toe aan elk criterium en vatten deze gewogen criteria samen in een "herstelbaarheids-score" voor het product. De iFIXIT-scorekaart is een semi-kwantitatieve methode die ontwikkeld werd om het gemak van herstel voor ICT-producten te evalueren. Een ander voorbeeld zijn de Oostenrijkse technische voorschriften ONR 192 102: 2014 die kunnen worden toegepast op zowel grote huishoudtoestellen (witgoed) als op kleine elektrische en elektronische apparaten (bruingoed).

Kwantitatieve methoden gebruiken meetbare gegevens om een herbruikbaarheidsindex te berekenen. De Ease of Disassembly Metric (eDiM) methode berekent bijvoorbeeld de vereiste demontage- en hermontagetijd. eDiM kan worden gebruikt om de herstelbaarheid te beoordelen, aangezien demontage- en hermontage-activiteiten een belangrijk onderdeel van het herstelproces vormen.

In de tweede taak van deze studie worden horizontale herstelcriteria voorgesteld. De ontwikkelde evaluatiemethode is een semi-kwantitatieve methode. Er wordt een algemeen kader voorgesteld dat een duidelijke en zinvolle structuur biedt voor elk herstelbaarheidscriterium volgens het criteriumtype en de bijbehorende herstelstap.

In totaal zijn 24 criteria voorgesteld en elk criterium ontvangt een score afhankelijk van de geselecteerde optie. De verschillende opties per criterium zijn zo gedetailleerd mogelijk uitgewerkt en waar mogelijk zijn meetbare gegevens aangewend. Er zijn criteria gedefinieerd rond het verschaffen van specifieke informatie, zoals uitleg bij foutmeldingen, uitgebreide demontage-instructies of referenties van wisselstukken. Andere criteria beoordelen het ontwerp van het product voor herstel, zoals het gemak van demontage of het individueel kunnen vervangen van prioritaire onderdelen. Het criterium met betrekking tot het gemak van demontage, is gebaseerd op de kwantitatieve eDiM-evaluatie. Tenslotte zijn er ook criteria die de aangeboden hersteldiensten van de fabrikant tijdens de levensduur van het product beoordelen. Hoewel de ontwikkelde criteria zich richten op de technische haalbaarheid van herstel, zijn voor sommige criteria, zoals de toegang tot reserveonderdelen en hersteldiensten, de kostenaspecten in rekening gebracht.

Over het algemeen zijn de gewichten van het generisch meetinstrument vrij gelijkmatig verdeeld, met iets meer nadruk op productontwerp (38% van de totale score), vergeleken met informatievoorziening (29%) en hersteldiensten aangeboden door de fabrikant tijdens de gebruiksfase (33%). Afhankelijk van het producttype zouden deze gewichten verder aangepast kunnen worden om meer nadruk op bepaalde criteria te leggen.

Sommige criteria kunnen afhankelijk zijn van de prioritaire onderdelen. Vóór de start van de herstelbaarheidsbeoordeling moet een lijst van prioritaire onderdelen worden opgesteld, indien deze nog niet beschikbaar is voor de relevante productgroep. Prioritaire onderdelen zijn onafhankelijk van de moeilijkheden die reeds ervaren worden bij het vervangen of herstellen maar moeten geïdentificeerd worden aan de hand van volgende aspecten:

- Meest voorkomende storingen of misbruiken van producten
- Onderdelen die het meest waarschijnlijk worden vervangen of hersteld
- Bijdrage van onderdelen aan de belangrijkste functie van het product

De ontwikkelde methodologie biedt een volledige set van criteria met betrekking tot de verschillende aspecten van herstelbaarheid gedurende de gehele reparatiecyclus. Een aantal parameters moet echter worden gedefinieerd op productgroep niveau, zoals:

- Referentiewaarde voor de demontage (eDiM)
- Lijst met prioritaire onderdelen en veelvoorkomende falingen

- Detailniveau van de nodige herstelinformatie
- Duur van de periode waarbinnen hersteldiensten ter beschikking zijn (dit zou afhankelijk kunnen zijn van de verwachte gemiddelde levensduur van het product)
- Relatieve kosten en beschikbaarheid van reserveonderdelen

In een volgende stap van deze studie wordt de ontwikkelde evaluatiemethode toegepast op een aantal specifieke gevallen voor wasmachines en stofzuigers. Voor elke case study wordt eerst de geselecteerde productgroep gekarakteriseerd, het beoordeelde productmodel wordt kort beschreven en ten slotte wordt de herstelbaarheidsscore berekend door het toepassen van de herstelbaarheidscriteria. In een bijkomende taak worden de potentiële economische gevolgen voor de consument gekwantificeerd.

In alle gevallen is de herstelbaarheidsscore voor een professionele hersteller hoger dan voor een consument, onder andere wegens de beperktere inhoud van de beschikbare informatie voor consumenten. Bij de stofzuigers is ook de toegankelijkheid van onderdelen beter voor professionele herstellers in vergelijking met consumenten.

Een aantal uitdagingen zijn vastgesteld bij het toepassen van de ontwikkelde methode. Deze uitdagingen dienen verder onderzocht te worden om de huidige voorgestelde criteria verder te verfijnen.

Een belangrijke uitdaging is de identificatie van prioritaire onderdelen. Aangezien alle componenten kunnen falen, is er een afsnijregel nodig om te voorkomen dat alle onderdelen als prioritair geïdentificeerd worden. Verschillende opties zijn mogelijk. Een afsnijregel kan worden gedefinieerd als een minimum aantal onderdelen (bijvoorbeeld de 5 onderdelen met de hoogste faalkans) of op basis van het afdekken van een minimaal aandeel van mogelijke falingen (bijvoorbeeld 75% van de storingen). Daarenboven is het mogelijk dat binnen een specifieke productgroep een geïdentificeerd prioritair onderdeel niet relevant is voor alle productmodellen, zoals koolborstels voor wasmachines. Omdat producten voortdurend verder worden ontwikkeld, kunnen het aantal en het type prioritaire onderdelen in de loop van de tijd veranderen.

Bovendien is de beschikbaarheid van reserveonderdelen door derden niet gemakkelijk te beschouwen in de herstelbaarheidsevaluatie van een product. Ten eerste zijn fabrikanten zelf niet geheel verantwoordelijk voor de verdere distributie stroomafwaarts van (originele) onderdelen. Ten tweede zijn de compatibiliteit en kwaliteit van de reserveonderdelen aangeboden door derden moeilijk te verifiëren. Bijkomend kunnen sommige belangrijke onderdelen, zoals de motor, gedekt worden door een verlengde garantie. In de huidige studie werden deze (prioritaire) onderdelen niet verschillend behandeld, aangezien vervangingen onder verlengde garanties meestal niet volledig kosteloos zijn.

Een andere uitdaging waarmee het onderzoeksteam werd geconfronteerd, is het onderscheid tussen onderhoud, herstel en upgrade. Bij het begin van het project was vooropgesteld om deze verschillende acties duidelijk te onderscheiden. In de praktijk kan echter een onderhoudsinstructie ook dienen voor herstel (bijvoorbeeld het reinigen van een filter). Ook in consumentenonderzoeken werden filters vaak beschouwd als defecte onderdelen waarvoor herstel nodig is, terwijl dit door de fabrikant wordt beschouwd als een onderdeel dat regelmatig moet vervangen worden in het kader van onderhoud.

In het algemeen worden apparaten steeds complexer omdat ze meer elektronische componenten bevatten. Het feit dat er meer (elektronische) componenten in een product worden geïntegreerd, vergroot de waarschijnlijkheid dat een storing optreedt tijdens de levensduur van het product. Om een grotere materiaalefficiëntie te bereiken door de verlengde productlevensduur, zal het niet voldoende zijn om meer herstelbare producten van fabrikanten te verwachten. Ook consumenten moeten zich ervan bewust zijn dat minder complexe producten doorgaans robuuster zijn. De consument zou alleen producten met specifieke kenmerken moeten kiezen als dit relevant is voor zijn beoogde gebruik.

Bovendien moeten de verschillende belanghebbenden samenwerken om te bepalen welk type producten en welk type storing door consumenten kan worden gerepareerd door zelfherstel. Een consument zou een aantal (eenvoudige) storingen kunnen herstellen zonder dat dit gepaard zou gaan met een onaanvaardbaar veiligheidsrisico. In andere gevallen is echter herstel door een professionele hersteller vereist. In die gevallen moet het doel zijn om de aangeboden hersteldiensten te verbeteren door de toegankelijkheid voor consumenten te vergroten, kosten te verlagen en tijdelijke vervangproducten aan te bieden tijdens de herstelwerken.

Een beleidsinstrument dat kan worden gebruikt, is het verlengen van de garantieperiode. De garantieperiode kan per productgroep worden bepaald, afhankelijk van de gemiddelde verwachte levensduur. De economische evaluatie die in dit onderzoek is uitgevoerd, bevestigt dat een verlengde garantie gunstig is als een voldoende deel van de verwachte levensduur door de garantie wordt gedekt. Bovendien is vastgesteld dat bedrijven erin slagen om het aandeel teruggestuurde producten tijdens de garantieperiode onder de 3% te houden. Allicht zal een vergelijkbare doelstelling worden gehanteerd voor de verlengde garantieperiode. Er moet echter verder onderzoek worden uitgevoerd om alle gevolgen van een dergelijke verlengde garantie te evalueren. Zelfs als de verlengde garantie gratis is, is de kans groot dat dit deze maatregel de aankoopprijs verhoogt. In het geval van producten van lagere kwaliteit, in de meeste gevallen geproduceerd tegen lagere kosten, kunnen bedrijven vaker besluiten om de gefaalde producten te vervangen in plaats van ze te herstellen, wat niet zou bijdragen tot het algemene doel van een verlengde levensduur om de materiaalefficiëntie te verhogen.

Verder onderzoek is ook nodig om de correlatie te bevestigen tussen de herstelscore verkregen met de voorgestelde methode en het gemak van herstellen in de praktijk. Ondertussen kunnen een aantal specifieke onderdelen worden geselecteerd om consumenten beter te informeren. Voorbeelden zijn de mogelijkheid om prioritaire onderdelen te vervangen of te upgraden, het gemak van demontage uitgedrukt met de eDiM-metriek of de onderhoud en hersteldiensten die worden aangeboden tijdens het gebruik van het product. Bovendien heeft de economische impactstudie aangetoond hoe belangrijk een voluntaristische strategie is in het kader van herstelbeslissingen van de consument. De levenscycluskosten per jaar nemen af wanneer de consument een groot aantal herstellingen van een apparaat toestaat. Deze opmerking geldt zelfs in het geval dat de herstelling hoge kosten met zich meebrengt. Alleen in het geval dat het apparaat het einde van zijn verwachte levensduur nadert, zou de consument terughoudend moeten worden in het herstellen van defecte apparaten.

Het bredere gebruik van de ontwikkelde herstelbaarheidscriteria moet verder worden onderzocht door de methode op een groter aantal producten toe te passen. Een volgende stap zou kunnen zijn om te zorgen voor een consistent gebruik van het meetinstrument en de robuustheid van de verkregen resultaten (repliceerbaarheid van de methode). Een testpanel van geselecteerde belanghebbenden kan de ontwikkelde methode bijvoorbeeld toepassen in een proefproject. Een dergelijk proefproject met verschillende belanghebbenden in de toeleveringsketen kan ook worden gebruikt om verticale herstelcriteria voor specifieke productgroepen te ontwikkelen.

Andere stappen die op Benelux-niveau als laboratorium in Europa kunnen worden onderzocht, zijn het vergemakkelijken van de toegang tot hersteldiensten voor de consument (en andere informatie mogelijkheden zoals etikettering) en de ontwikkeling van bedrijfsmodellen om aan te tonen dat herstelbaarheid opportuniteiten kan bieden aan bedrijven.

Chapter 1: Introduction

1.1 Scope and objective

In its 2015 Communication "Closing the loop - An EU action plan for the Circular Economy" the European Commission sets a plan to keep the added value in products for as long as possible and to design out waste.

In this context several complementary strategies could be explored:

1. improved material recyclability and recycling;
2. service based consumption and production modes including remanufacturing;
3. extending product life time by increasing repairability and reuse of products put on the market.

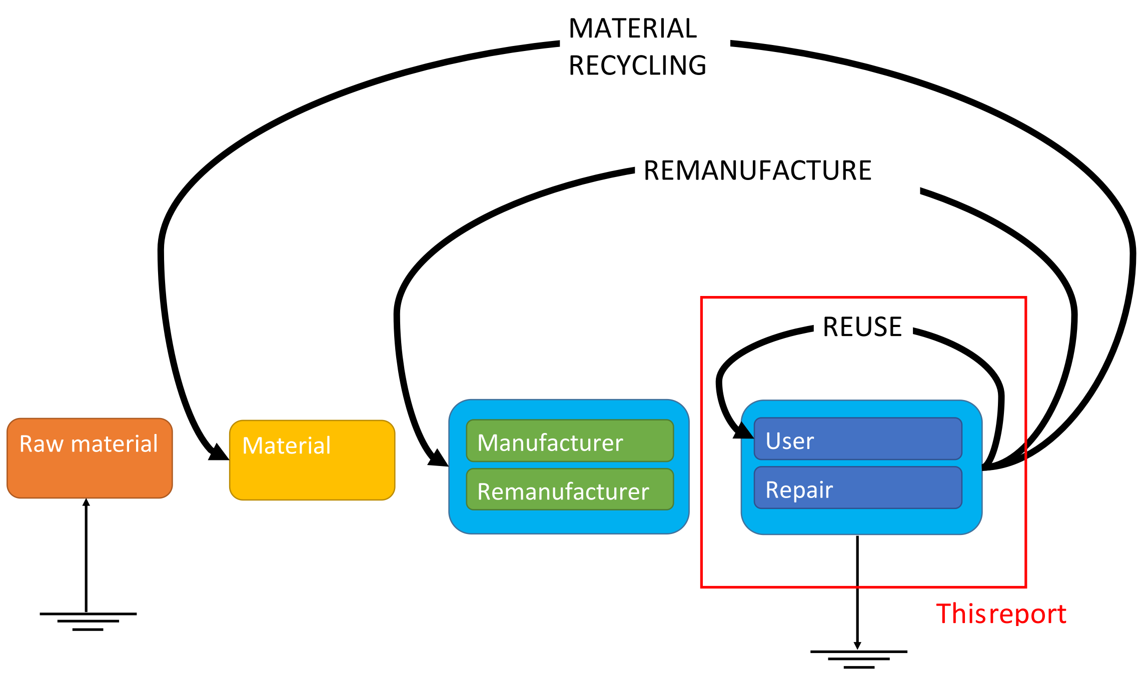


Figure 1: Complementary strategies to move towards a more circular economy, adapted from (1)

As a consequence of our current throw-away society and the lack of incentives for manufacturers to apply eco-design, consumer goods are nowadays less durable and repairable than in the past and the average product lifetime of many products is decreasing (2). Repairing modern electrical and electronic equipment is becoming increasingly difficult and following obstacles to repair todays electric and electronic products have been encountered:

- Lack of appropriate repair information (specially for independent repair operators): no free access to service manuals and/or failure detection software and hardware;
- Lack of access to and high costs of spare parts: costs of repair are higher than purchasing a new appliance;
- Rapid change of product design makes it increasingly difficult to repair a product; and

- Difficulty to non-destructively disassemble products for repair is increasing, for example by the increasing application of snap-fits and adhesives.

These factors significantly contribute to the costs associated with repair, making direct replacement of a product often the most straightforward option for the consumer. Therefore, the Benelux Union has requested this study to investigate extending product life time by exploring repairability criteria for products. The Benelux Directive on the practical application of the circular economy was signed in December 2016 and has provided the legal framework for Belgium, the Netherlands, Luxembourg and the Benelux Secretariat-General to initiate the research presented in this report. This research will also support ongoing European standardization processes at CEN-CENELEC and ongoing further research on repairability of product performed at the European Joint Research Centre (JRC).

The overall aim of this study is to evaluate and, if possible, quantify the ease of repair for energy-related products (ErPs) considering the economic impact from a consumer perspective. In order to meet this objective, repairability criteria for ErPs are proposed. The repairability criteria can either be horizontal criteria that can be applied to a variety of product groups or it can be vertical product group specific criteria that can be adapted to be applied to other product groups. The implementation of these criteria into a product standard could be used to:

- set minimum requirements that can help making products last longer;
- make relevant information available, allowing consumers to choose to purchase products that can be more easily repaired and upgraded and whose parts and materials can be better reused or recycled;
- drive innovation by creating incentives for manufacturers to develop more eco-friendly products, so they can better differentiate themselves from their competitors.

Furthermore the developed criteria and proposed testing method should be:

- non-ambiguous, allowing minimal freedom of interpretation;
- effective in extending the product life;
- provide clear guidelines for industry to improve the product design; and
- verifiable by Competent Authorities.

Finally, this study identifies best practices for repairability within a selected product group from a technical and economic perspective, whereas it will be the aim to compare product features, such as additional warranty, ease of repairability, and not the product models as such.

1.2 Repair activities

Repair activity can be conducted in different ways. It can be done by manufacturer's or retailer's after sales service (in house), it can be done by professional repairs under contract with manufacturers (outsourced), it can be done by a repair company (independent professional repair) or it can be done by the customer (self-repair). Customers attempting self-repair often rely on repair guides made available by third parties on the internet or seek support from experienced volunteers at repair café's. Depending on the repair route, different challenges will arise and this must be taken into account when assessing the repairability of products. *Figure 2* below provides an overview of the different actors in the repair sector.

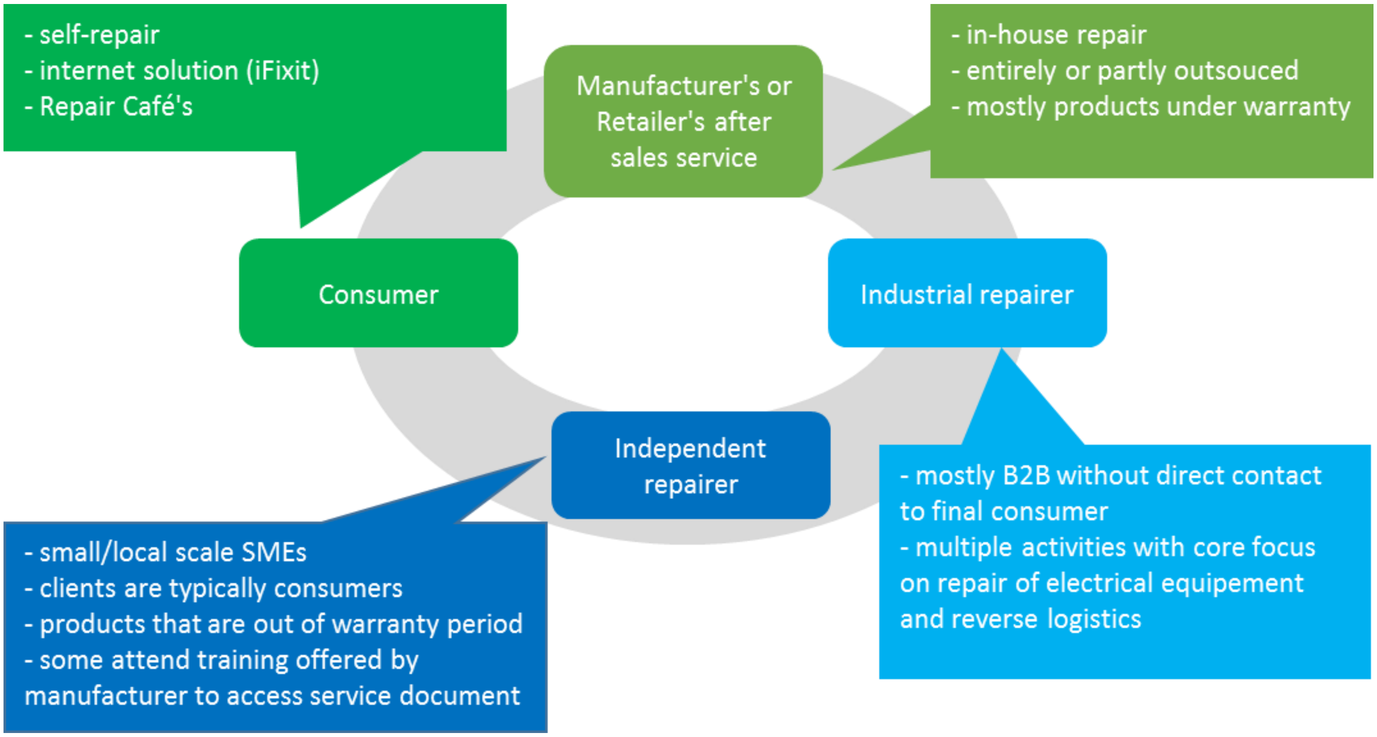


Figure 2: Different potential actors in the repair cycle - adapted from(3)

In general, repair is necessary when a product or a part of a product fails to fulfil its function or when the product's performance decreases due to decay or damage (4). However, before repair takes place a number of decision steps are considered.

If the product is still under warranty, the consumer will most likely turn to the manufacturer's or retailer's after sales service. It will be assessed whether the product is technically repairable by the in-house repair team or by an industrial partner (outsourced repair). Even if the product is technically repairable, the service provider will also consider the cost, required effort and time. The outcome of decision to repair can vary depending on the service provider but also on the product type. In case the product is not repaired the consumer will receive a new product. If the product is not or no longer under warranty, the consumer may also consider self-repair or turn to an independent repairer. Similar assessments of technical and economic repairability will take place to feed the decision to repair. *Figure 3* below shows the decision process that occurs when a product fails.

Although the economic impact of the repair activity on the lifecycle costing of the product will be considered in this study, the main focus is ease of technical repairability.

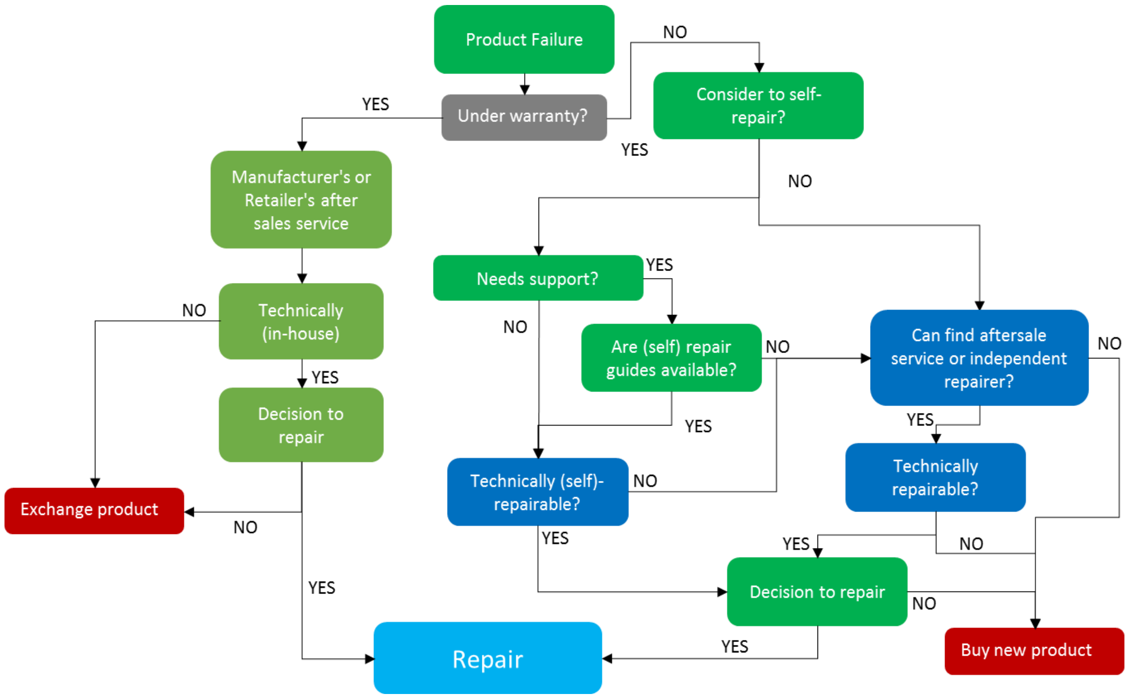


Figure 3: Decision process for repair - adapted from (3)

1.3 Project approach

KU Leuven undertakes this study in close collaboration with VITO. Figure 4 provides an overview of the followed approach for this study.

In the first task a background study has been carried out to identify existing initiatives or standards related to repairability criteria. Based on this literature study some key definitions have been proposed and the most relevant repairability criteria are summarized.

In the second task horizontal repairability criteria are proposed. A general framework has been developed that provides a clear and meaningful structure for each repairability criteria according to the criteria type and the related repair step.

In a next step, the developed criteria are applied in a specific case study (Task 3) and the potential economic impact for the consumer is quantified (Task 4).

The results of the different tasks are further analysed in detail and general conclusions and policy recommendations are made based on this analysis (Task 5).

The overall project deliverable is also presented to stakeholders and the obtained feedback is summarized to evaluate the feasibility of implementation of the developed methods in legislation and to identify opportunities for future research (Task 6).

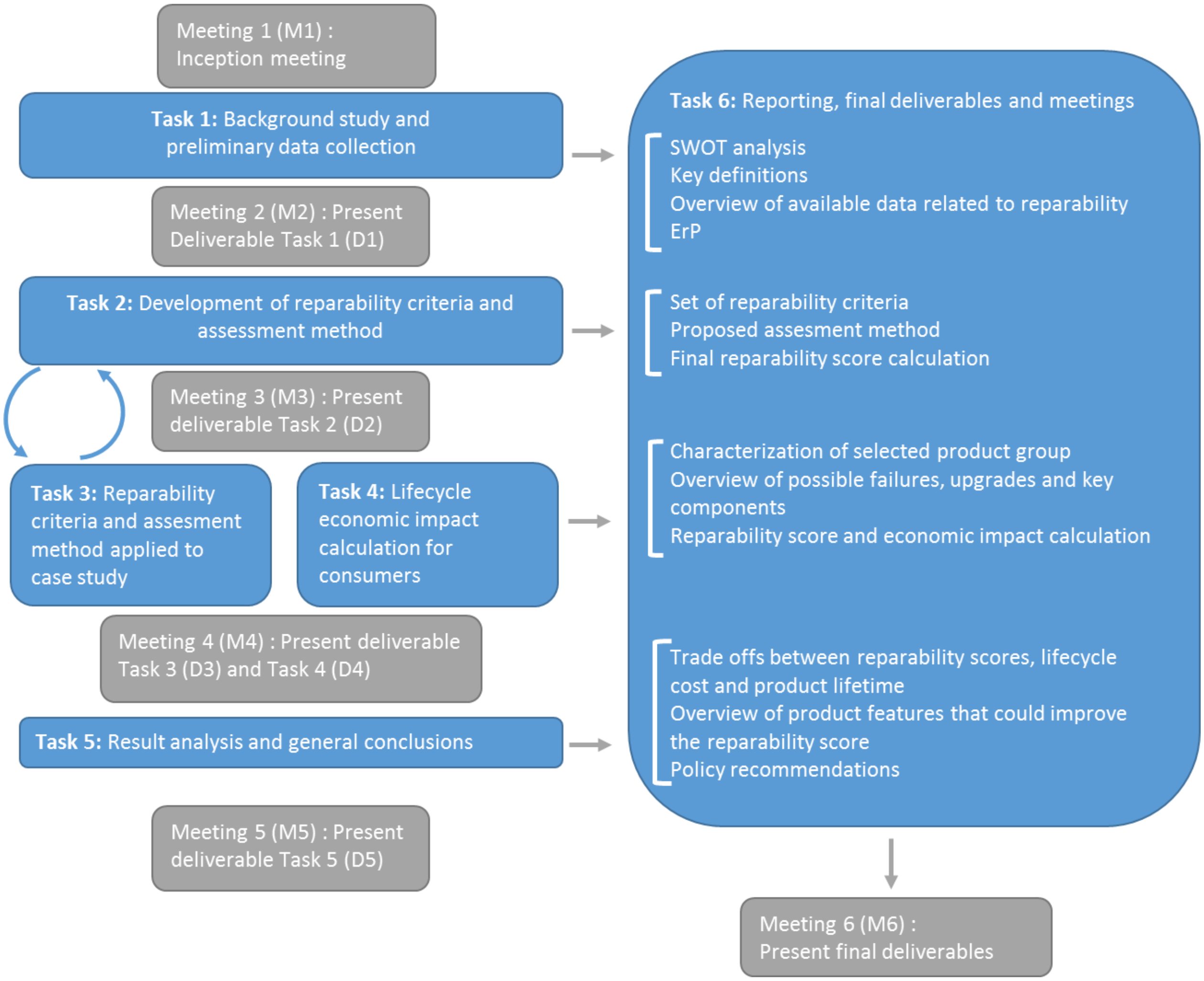


Figure 4: Followed approach and task structure for the presented research in this report

Chapter 2: Key definitions

2.1 Reparaibility

Different definitions of "repairability" can be found in literature:

- the ability and ease of product to be repaired during its life cycle (5)
- the ability to bring a product back to working condition after failure in a reasonable amount of time and for a reasonable price (6)
- the characteristic of a product that allows all or some of its part to be separately repaired or replaced without having to replace the entire product (7)

The proposed definition by the CEN-CELEC working group 3 includes many relevant elements of repairability however it does not specify the desired outcome of the repair (bringing a product back to working condition). Additional the main parameters that determine the feasibility of a repair (cost and time) are not included. Therefore, for the purpose of this study, 'repairability' is defined as follows:

→ the **characteristic of a product** that allows all or some of its part to be brought **back to working condition after failure** in a reasonable amount of **time** for a reasonable **price** without having to replace the entire product

2.2 Repair activities

In general repair takes place when a product or part of a product fails to fulfil its function or when the product's performance decreases due to decay or damage (4). *Figure 5* shows the different steps of the repair cycle.

The first step is to properly identify the product model in order to retrieve relevant repair information such as failure diagnostic guides, disassembly instructions or availability of spare parts. In a second step, the damage or failure has to be identified. In this step the technical repairability is assessed and the required further repair action, such as replacement of failed parts, are identified. To access these failed parts, complete or partial disassembly and subsequent reassembly is required. Before putting the product back in use, in many cases the repaired product is tested and/or reset.

Similar to repair, maintenance and upgrading often requires disassembly and reassembly of the products for the purpose of part inspection or replacement. Accordingly, most criteria used to assess the repairability will also be applicable to assess the ease of maintenance, upgradability and remanufacturing. However, maintenance has the objective to avoid failure and minimize the need for repair and upgrading goes beyond repair as it changes the capacity and/or functionality of the product. Therefore, this study focusses only on setting up methods and criteria to evaluate the repairability of energy related products.

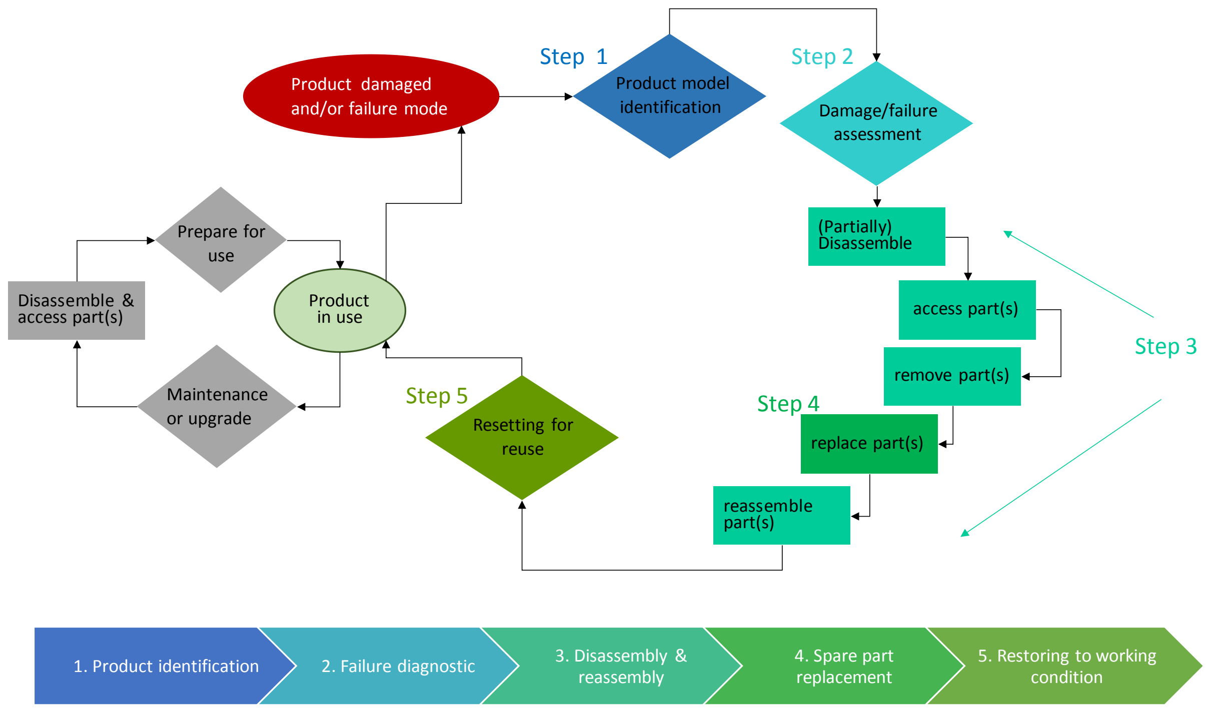


Figure 5: Overview of repair cycle

2.3 Priority part

Within the context of repairability, priority parts are commonly determined by the failure rate of individual parts. For example, priority parts are those parts that are exposed to a particular wear or material fatigue might have a higher failure rate (8). Priority parts are also defined as those parts which, typically, may break down within the scope of the ordinary use of a product (9). However, it is not because a part is not commonly repaired that it should not be defined as priority part, as in some cases repair is rarely performed due to the difficulty of the repair activity and/or limited availability of spare parts. It should also be considered that prioritisation of parts will be different in the context of upgradability or recycling (7).

Taking into account these considerations a priority part is defined as follows for the purpose of this study:

→ parts that are most likely to be repaired or replaced during normal service life of the product and/or parts that are characterized by a high assumed failure rate and/or are critical for the product to deliver the main desired function.

2.4 Disassembly

Different definitions of "disassembly" can be found:

- non-destructive taking apart of an assembled product into constituent materials and/or components (4)

- a process whereby an item is taken apart in such a way that it could subsequently be reassembled and made operational (10)
- a reversible process in which a product is separated into its components and/or sub-assemblies by non-destructive or semi-destructive operations which only damage the connectors/fasteners. If the product separation product is irreversible, this process is called dismantling (11)

For the purpose of this study partial or complete disassembly is defined as follows:

→ a **reversible** process in which a product is **separated into its parts** by non-destructive operations or semi-destructive operations which only damage the connectors/fasteners in such a way that it could subsequently be reassembled and made operational, possibly needing new connectors/fasteners.

2.5 Repair manual

Repair manuals should be easily accessible, readable, understandable (self-explanatory), free of charge and as simple as possible (12,13). Access to repair manuals can be facilitated by the use of Quick Response (QR) codes, which can be decoded to retrieve a link to access information. Repair manuals can contain the following information:

- Manufacturer's service centers (after sales services): address, phone and business hours can be provided to the consumer directly by the manufacturers or through retailers. This service should offer:
  - A substitute for the original product during the repair time
  - The possibility to get repair swiftly
  - Assistance in fault diagnosis
  - Support for repair operations
- Product maintenance instructions
- Instructions for disassembly of a product
  - Kind of repair tools needed and their availability
  - Information about type and number and location of connections
  - Description of actions that must be carried out to repair the product (basic fault diagnostic advice and troubleshooting tree)
- Index for spare parts: includes information on where to get spare parts and their cost

Asides from the content of repair manuals also the structure of the manual and ease of retrieving the required information for persons performing repair operations is of high importance.

2.6 Remanufacture

Remanufacturing is the process of returning a used product to like-new condition with a warranty to match (14). The process includes sorting, inspection, disassembly, cleaning, reprocessing and reassembly, and parts which cannot be brought back to original quality are replaced, meaning the final remanufactured product will often be a combination of new and reused parts (15).

Remanufacturing will typically take place in Product Service Systems and are often unfeasible for sold consumer products. These new business models are currently seen as part of the solution towards a more circular economy. However, the research presented in this report focusses on repair during the use phase of a consumer product.

2.7 Product lifetime

Four definitions of product lifetime are given in a study carried out by *BIO intelligence* for the French environmental and energy Agency, ADEME (16):

- The '**normative lifetime**' corresponds to the average operating time measured in specific test conditions, typically defined in a standards. This lifetime is not necessarily measured in time but may be measured in other units, such as number of cycles.
- The '**service life**' corresponds to the period of time during which the product is kept in operating state or ready-to-use mode by a given user. The '**total product service life**' is the sum of the product service life of each user.
- The '**detention time**' of a product by a user corresponds to the time between the entry into the household and the release of the product by this user, regardless of the product's condition. This includes storage times and possible repair activities. The total detention time is the sum of the detention periods of each user and corresponds to time between the purchase of the new product and the moment it is discarded as waste for the purpose of material recycling. The '**total detention time**' is thus greater than or equal to the product service life due to possible storage of the products in the households.
- The '**total product lifetime'** corresponds to the time between the end of the product's manufacture and its disposal, recovery or recycling. It differs from the total detention period because it includes the possible reuse of a product after it has been discarded as waste, as well as the shelf life before it is purchased for the first time.

These different definitions of product lifetime should be clearly distinguished from the average expected product lifetime (AEPL), which is often used in statistical studies and which refers to the average length of detention of the devices at a given time .

Chapter 3: Overview of existing initiatives

3.1 Introduction

There are many existing and emerging initiatives that aim to evaluate the environmental performance of products. In the current context of moving towards a (more) circular economy, product repairability is in many cases part of such environmental performance evaluations. There are three evaluation methods: 1) qualitative 2) semi-quantitative; and 3) quantitative.

Qualitative evaluation methods generally consist of a number of criteria that need to be fulfilled in order to obtain a label, such as Blue Angel, Nordic Label or European Eco-label.

Semi-quantitative evaluation methods assign a weight to each criteria and sum up these weighted criteria which results in a "repairability score" for the product. Examples for this are the iFIXIT score card and the Austrian Technical Rules ONR 192 102:2014.

Quantitative methods use measurable data to calculate a reusability index or metric. For example, the Ease of Disassembly method (eDIM) calculates the required disassembly and reassembly time, which can also be used to assess the repairability since disassembly and reassembly activities are an important part of the repair process.

In the next section of this chapter an overview of initiatives that include repairability criteria are summarized.

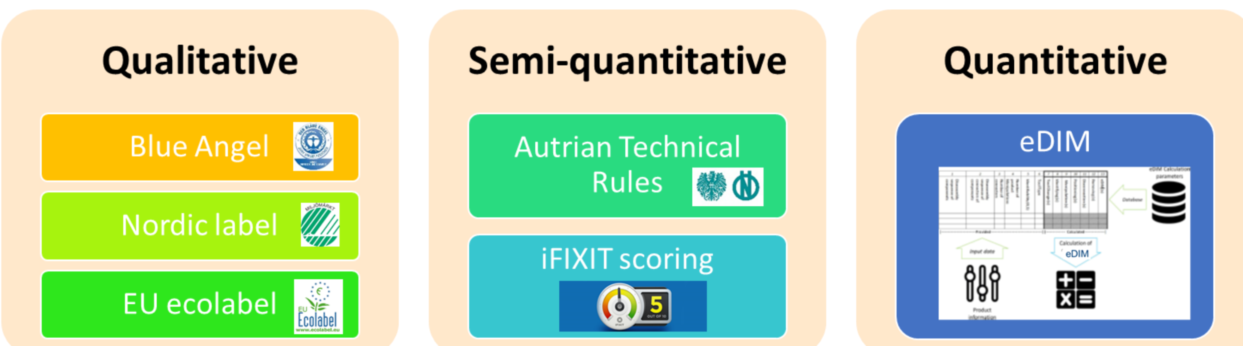


Figure 6: Overview of existing initiative that include repairability criteria

3.2 Qualitative assessment methods

There is a wide range of labelling schemes that apply to products but only a handful that apply to electric and electronic products and even less that included specific criteria for repairability.

- **Blue Angel label**
  The Blue Angel (Der Blaue Engel) is a German certification for products and services based on their environmentally friendly aspects. The label is owned by the German Authorities and is verified by the certification company RAL gGmbH. The label is awarded on the basis of specific set of requirements/criteria developed by the Federal Environment Agency and the Independent

Environmental Label Jury. The continuous development and update of the criteria is supported by environmental and consumer organizations as well as manufacturers.

The Blue Angel guidance documents includes a few relevant definitions:

- The term "**universal tools**" is understood to mean those tools that are usually generally (commercially) available in the retail trade such as pliers, screwdrivers, knives or hammers etc.
- **Spare parts** are those parts which, typically, may break down within the scope of the ordinary use of a product - whereas those parts which normally exceed the life of the product are not to be considered as spare parts.
- **Quick and easy disassembly:**
  - it must be possible to separate the connections concerned by the use of ordinary tools and the points of connection must be easily accessible, and
  - disassembly instructions must be made available

Specific criteria for electric and electronic products have been developed for a wide range of product group categories but not all include criteria related to repairability. *Table 1* shows for which product groups specific repairability criteria are currently included. The similarities identified between the different reviewed criteria documents underline the potential for the development of horizontal criteria that are relevant to all products.

Table 1: Overview criteria type identified per product group for Blue Angel Label

	Blue Angel				
	Mobile phone	**PC, Video Conference & STB**	**TV**	**Vacuum**	**Coffee machine**
Instruction on maintenance					
Instruction on repair					
Performance/durability tests				X	
Upgradability		X			
Ease of disassembly	X	X	X	X	
Priority parts	X				
Spare parts supply		X	X	X	X
Warranty/Guarantee					

- **Nordic Swan Label**

The Nordic Swan Ecolabel was established in 1989 by the Nordic Council of Ministers with the purpose of providing an environmental labelling scheme that would contribute to a sustainable consumption. The Nordic Swan Ecolabel is a voluntary eco-labelling scheme that evaluates a product's impact on the environment throughout the whole life cycle. Each product group has overriding general criteria requirements as well as product-specific requirements. The criteria are developed by experts from environmental organisations, industry or the Norwegian government and are revised every three to five years in order to continue the process of reducing a product or service´s environmental impact.

All requirements must be fulfilled and specific documentation needs to be provided by the applicant. The Nordic Ecolabel has developed criteria for a number of electric and electronic products and a number of them include criteria related to repairability, as shown in the table below.

Table 2: Overview criteria type identified per product group for Nodic Swan Label

	Nordic label			
	White goods	**PC**	**Imaging equipment**	**TVs & projectors**
Instruction on maintenance	X		X	X
Instruction on repair				
Performance/durability tests				
Upgradability		X		
Ease of disassembly	X	X	X	X
Priority parts			X	
Spare parts supply	X	X		X
Warranty/Guarantee	X			X

- **European Eco-label**
  The European Eco-label is a voluntary scheme, which means that producers, importers and retailers can choose to apply for the label for their products. The functioning of the European Eco-label is set through a Regulation of the European Parliament and of the Council. Its daily management is carried out by the European Commission together with bodies from the Member States and other stakeholders. Following consultation with the European Union Eco-labelling Board (EUEB), the European Commission, Member States, Competent Bodies and other stakeholders may initiate and lead the development or revision of European Eco-label criteria. This process requires significant resources and time and takes on average 2 years.

  The European Eco-label criteria are a list of requirements to be fulfilled by the applicant through declarations and test reports. The European Eco-label criteria exist for a limited number of electronic equipment and a few of them include criteria related to repairability. The recently published criteria for computers includes the requirements related to repairability shown in the table below.

Table 3: Overview criteria type identified per product group for European Ecolabel

	EU Ecolabel		
	PC	Imaging equipment	TV
Instruction on maintenance	X		
Instruction on repair	X		
Performance/durability tests	X		
Upgradability	X		
Ease of disassembly	X	X	X
Priority parts	X	X	
Spare parts supply	X	X	X
Warranty/Guarantee	X	X	X

3.3 Semi- Quantitative assessment methods

The research presented in this report focuses on scoring schemes applied in Europe and publicly available information. For example, the NFS 426 standard for server was not yet finalized at the time the analysis for this study was done and the US-based EPEAT UL 110 (mobile phones) criteria are not publicly available.

- **Austrian Technical Rules - ONR 192 102:2014 "Label of excellence for durable, repair-friendly designed electrical and electronic appliances"**
  The Austrian Standard Organization publishes ÖNORM Standards which are based on broad consensus. The Austrian Standard Organization also publishes ONR (ON Rules) that are quickly available normative documents. A durability mark (ONR 192102) for electrical and electronic appliances (EEA) (white and brown goods) designed for easy repair was published in 2006 and reviewed in 2014.

  The Austrian normative document contains a set repairability criteria for white goods (40 criteria) and brown goods (53 criteria) respectively. A number of criteria are marked as mandatory requirement (17 for white goods and 21 for brown goods). The remaining criteria are optional and can contribute to an overall 'durability' score. At least 30 points need to be obtained from the 'general requirements' and 15 points form the service delivery part. The 'general requirements' are mostly related to product design while the 'service delivery' concerns the quality of available information and provided service such as, for example, additional warranty. Depending on the final overall score the products will receive a rating between 5 and 10 which will correspond to a qualitative rating of Good (5-6), Very good (7-8) or Excellent (9-10).

  There is no list of definitions provided in the Technical Rule Document.

- **iFixit repairability score for smartphones and computers**
  iFixit was founded in 2003 in the United States and provides free repair manuals mainly for electronic products. The manuals are established with the contribution of experienced people. iFixit also provides tools for repair and spare parts which can be ordered through their web shop.

iFixit has a repairability scoring scheme for a number of communication devices: phones, tablets and laptops. iFixit's engineers score the repairability of each product based on their experience during disassembly of the product. The given score ranges between zero and ten, ten being the easiest to repair. Points are docked based on the difficulty of opening the product, the types of fasteners found inside, and the complexity involved in replacing major components. Points are awarded for upgradability, use of non-proprietary tools for servicing and component modularity.

The scoring is done based on a set of criteria that each represent a number of points (5 or 10). The maximum score that can be obtained, which is the case if all criteria are met, is 100. The final score is then divided by 10 to result in a score from 0 to 10 for each product model.

The qualitative scoring scheme is currently under further development in collaboration with TU Delft. A first proposal of new repairability criteria developed for brown goods can be found online (17). In total 20 criteria are evaluated and for each item 1 of 3 option must be selected resulting in 0, 1 or 2 points. The maximum achievable score is thus 40. The final scores are re-scaled by dividing by 4 to achieve a score between 0-10, similar to current iFIXIT scoring scheme.

In addition, iFIXIT and TU Delft are also collaborating on a excel based tool to assess the ease of disassembly based on the MOST methodology. This is similar to the eDIM method that KU Leuven developed in collaboration with JRC. The eDIM methodology is further explained in next section on quantitative assessment methods

Finally, it is iFIXIT's long term goal is to combine both a qualitative assessment based on a set of specific criteria (check list) and the quantitative assessment that evaluates the ease of repair based on estimate required time to disassemble and reassemble products or part of products during repair activities.

3.4 Quantitative assessment methods

The (partial) disassembly and reassembly of products to replace or repair specific parts are a key part of the identified repair activities. Actually measured disassembly time will vary greatly depending on experience of the operator, presence of required tools and upfront provided knowledge. The disassembly time is expected to be lower with increasing knowledge provided to the operator, for example related to the preferred disassembly sequence, and with increasing experience of the operator. Therefore, different approaches have been developed in an attempt to quantify the ease of disassembly in a standardized manner (18–21). However these methods are not well suited to compare a wide range of products with robust results because they are too complex and/or are based on subjective input data. Therefore, this study will focus on the eDIM method as quantitative method (22).

- **eDIM methodology**
  The eDIM is developed by KU Leuven in collaboration with JRC to evaluate the ability or easiness with which components can be disassembled from products to facilitate repair, remanufacture and/or reuse (22,23). The method calculates the "ease of Disassembly Metric" (eDIM) and aims at assessing the effort needed to completely or partially disassemble a product. For this method, a database of disassembly tasks was built based on the Maynard Operation Sequence Technique (MOST), which provides values for elementary manual movements. The disassembly and reassembly effort is represented by the expected time necessary for disassembly tasks and is, therefore, expressed in seconds. The method is applicable to a broad range of products, as the time and motion method MOST is used to model the defined disassembly tasks.

  Each of the six determined disassembly tasks, (1) Tool change, (2) Identifying, (3) Manipulation, (4) Positioning, (5) Disconnection, and (6) Removing, are modelled using the time and motion method MOST to determine the time needed to perform these tasks, taking into account both product and connector properties.

  The output of the method can be used for evaluating eco-design improvements regarding ease of disassembly. The method is regarded as reproducible and repeatable as it builds on a widely applied methodology for work measurements, in which the accuracy of time estimations is statistically grounded. Since MOST focuses on basic motions, eDIM could be applied to all product groups and the time needed to remove a specific component by all kinds of manual disassembly tasks could be calculated. In addition, eDIM can be used to model the disassembly time for novel connectors with different types of tools, providing the required flexibility to serve as a generic method for policy measures and to incorporate an extensive range of products and fasteners.

3.5 Analysis of selected criteria

The relevant identified repairability criteria from literature are discussed in more detail in this section.

Table 4 provides an overview of the analysed repairability criteria. The criteria have been grouped in three main types:

1. Criteria related to provision, availability and accessibility of information
2. Criteria related to the product features and design choises
3. Criteria related to the offered services during the use of the product

Table 4: Overview analysed criteria grouped per criteria type

Information requirements	Requirements on product design	Requirements on provision of services
Servicing guidance	Durability	Availability of spare parts
Failure identification	Test software/test mode	Extension of warranty period
Repair guide	Upgradability	Take back system
Information on spare part	Priority parts/key components	
	Ease of disassembly (including tools, connection, force, standardization, modularity, accessibility, time, skills)	

- **Information requirements**

Servicing guidance

The provision of adequate maintenance or servicing guidance can avoid premature failure and contribute to a longer product or component life time and prevent the need for repair. The Austrian Technical Rules and Nordic Swan label require a regular maintenance guidance to be provided. This can for example include the regular cleaning of filters and pumps and the removal of deposits. The reasoning behind this is that adequate maintenance can avoid need for repair and increase product life time. Even though maintenance is considered to be out of scope for a repairability assessment, the service manual contains valuable information for repair because some activities might be very similar.

Failure identification

Manufacturers usually only provide detailed information and access to relevant fault diagnosis software to selected repair service providers under contract. However, to allow self-repair and the repair of products by independent third parties, fault diagnosis software and/or hardware should also be public available where relevant. Unfortunately, only the Austrian Technical Rules include criteria related to the ease of failure identification. The Technical Rules require the software driven parts to have the ability to display errors and their meaning must be clearly described in the user guidance. Furthermore, it should be possible for all repair companies (not only authorized or contracted by manufacturer) to access the error codes and instructions for recovery.

Repair guide

To effectively extend the life time of products, access to repair service information for all independent reuse and repair centers of the after-sales service is important. Therefore, most schemes include one or more criteria related to repair or disassembly instructions.
The Blue Angel labelling scheme requires the provision of instructions for the professional disassembly. The criteria specify that these free-of-charge instructions must be presented either in video format or in writing using photo documentation and drawings.

The Nordic Swan Ecolabel only requires the provision of an exploded diagram of the product labelling the main components and identifying any hazardous substances present in components. This can be in written or audiovisual format.

The European Ecolabel requires user instructions to be provided. The user instructions must include:

- Repair information regarding who is qualified to carry out repair operations, including contact details as appropriate.
- Clear disassembly and repair instructions to enable a non-destructive disassembly of products for the purpose of replacing key components or parts for upgrades or repairs.
- Information to let the user know where to go to obtain professional repairs and maintenance service, including contact details. Servicing information provision should not be limited exclusively to the applicant's Authorized Service Providers.

The Austrian Technical Rules require the provision of up-to-date information for safety-relevant measures necessary during repair operation. This information must be publicly available and cannot be limited to repair companies under contract of the manufacturer. Furthermore, the Technical Rules also require the user instructions to include contact details (address, phone, and business hours) for repair support. Additionally all illustrations/drawings that are necessary for a complete description of the repair of the device, such as wiring diagram, exploded diagram, function description, program scheduling and error search can be made available to achieve additional points.

The iFIXIT criteria includes a criteria for including repair information/diagrams with product or freely available on the internet. The format and content of the required information are however not mentioned.

<u>Information on spare part</u>

Because many failures cannot be repaired without spare parts, the consumer should also be provided with clear and concise information related to availability of spare parts.

The Blue Angel labeling scheme includes requirements about the supply of spare parts. Additionally the product documentation must contain information related to this guaranteed availability of spare parts.

The Nordic Swan label requires information to be provided related to the supply of spare parts for specific period after product was last produced. Furthermore, the applicant must prepare information material to the service personal and the users informing about how parts wear out and how these parts shall be recycled or reused.

The European Ecolabel requires users to be informed about the guaranteed availability of spare parts.

The Austrian Rules require the provision of information related to the availability of spare parts including a reference list of spare parts providers with contact details.

- **Requirements on product design**

Durability

The Blue Angel label and the European Ecolabel include requirements for durability testing of the product or some of the product's components. Even though durability testing is important to extent products lifespan and minimize the need for repair, it does not demonstrate enhance ability of the product to be repaired. Therefore, durability requirements are not considered relevant for repairability assessment to be developed in this study. However, the overall expected lifespan of products and their parts can influence other reparability criteria, such as availability of spare parts and the identification of priority parts.

The Blue Angel Label specifies that the following durability requirements for *vacuum cleaners*:

- The motor shall have a minimum service life of 600 hours
- The suction nozzle must be able to withstand the impact of at least 600 drum rotations (or 1200 falls from as high as 80 cm).
- The suction hose must withstand at least 40,000 deformations.
- The appliance must survive a threshold and doorpost impact test of at least 500 cycles.

The requirements can be verified through a test report according to DIN EN 60312.

The European Ecolabel for *personal, notebook and tablet computers* also includes durability requirements for portable computers. For the notebook computer model, mandatory durability tests are required related to shock, vibration and accidental drop. Additionally, at least one optional test is selected related to temperature stress, screen resilience, water spill ingress, key board lifespan or screen hinge lifespan. This approach is intended to give notebook manufacturers the flexibility to select the additional test(s) based on their priorities for the model, their target market segments and feedback from warranty returns. For tablets mandatory durability test are required related to accidental drop and screen resilience.

For each test a short specification is provided describing the main conditions and parameters for carrying out the test, together with the basic functional requirement(s) that shall be checked following the test. The main standardization reference for detailed design and specification of the test apparatus are IEC test methods (IEC 60068)

In addition, the European Ecolabel for *personal, notebook and tablet computers* includes durability requirements for rechargeable batteries. The functional performance requirements are more demanding if the rechargeable battery cannot be changed without tools. This performance is verified according to the IEC EN 61960 'endurance in cycles' test.

Test software/test mode

Currently, only the Austrian Technical Rules include requirements related to test software or test modes. The Austrian Technical Rules include similar criteria for both white goods and brown goods. The mandatory criteria require the accessibility in the switched on position for the purpose of troubleshooting during the repair work and the availability of a test mode for software driven parts. In test mode, the software must continue to work and have the ability to display errors. Finally, for brown goods, it must be possible to reset default value based on information provided or with the help of a reset button. An optional criteria, to achieve a higher repairability score, states that errors detected by the software should be shown by means of display, LED flashing or code.

Upgradability

Qualitative checklist based initiatives often include requirements related to upgradability, typically for software driven devices, such as computers (Blue Angel, Nordic Label & EU ecolabel). The Blue Angel label also includes upgradability criteria for video conferencing and set-top-boxes (Blue Angel).

- ***Video Conference systems***

  The Blue Angel label for Video Conference systems requires the possibility of a software update (e.g. to expand the functionality, increase the transfer quality or data security). The consumer information must include information about the option of software updates. The Blue Angel label for Set top boxes requires the possibility to update the software on the set-top boxes via the product menu
- ***Personal Computers***

  The Blue Angel label for computers requires the following enhancement options to be available:
  - Expandable RAM (applies to thin clients only if they are equipped with a processor, it does not apply to portable computers)
  - Possibility to install, replace and expand the mass storage unit (does not apply to thin clients and portable computers)
  - Existence of a minimum of two USB 3.0 ports.
  - Possibility to connect an external monitor (does not apply to integrated desktop computers).

The Nordic Swan label requires computers to be modular and the modules are foreseen to be replaced without the use of special tools. Additionally, the computer is upgradable by:

- primary memory expansion
- installation, exchange and expansion of mass storage
- installation and/or exchange of CD ROM, DVD and hard disk drive
- at least one additional interface for external storage media and other peripheral devices.

According to the Nordic Swan Label, notebook computers have different upgradability requirements but, at a minimum, the following expansions must be possible:

- primary memory expansion
- port for external monitor
- port for external keyboard and mouse
- at least one additional interface for external storage media and other peripheral devices.

For tablets (slates), the following is required according to the Nordic Swan label:

- storage expansion slot (example a SDHC slot)
- minimum 1 expansion port (contact) following industry standard for accessories
- support for external monitor, keyboard and mouse

Although the EU Ecolabel for computer includes an upgradability criteria, it only requires specific components to be replaceable. No provision is included for capacity expansion. Target components for repair and/or upgrade are discussed in the next section.

The iFixit scoring scheme awards points if the RAM and storage drive of the laptop is upgradable

Priority parts/key components

- ***Imaging equipment***

  For "**imaging equipment's**" both the Nordic Swan label and European ecolabel have identified some key components. The Nordic label for imaging equipment requires the implementation of a system to sort, re-cover and/or re-use consumer durables and parts that wear out as much as possible. Consumer durables and parts that wear out are defined as those parts that service personnel replace when the machine is serviced or that can be replaced by the consumer after reading the instructions for use. Additionally the Nordic Label includes a list of components that have to be recovered for reuse or recycling:

  - toner cartridges,
  - drum kits,
  - light-sensitive drums
  - residual toner containers

  The European Ecolabel for imaging equipment requires the products to accept remanufactured toner and/or ink cartridges.

- ***Personal Computer***

  The Blue Angel label for computers requires devices to be designed for easy disassembly to allow housing parts, chassis, monitor panel and electrical/electronic components (including printed circuit boards) to be separated as fractions and, if possible, recycled by material type.

  The European ecolabel for computers requires the following components to be easily accessible and exchangeable for the purpose of repair or upgrade by the use of universal tools (i.e. widely used commercially available tools such as a screwdriver, spatula, plier, or tweezers):

  - Data storage (HDD, SSD or eMMC)
  - Memory (RAM)
  - Screen assembly and LCD backlight units (where integrated)
  - Keyboard and track pad (where used)
  - Cooling fan assemblies (in desktops, workstations and small-scale servers).

  Additional target components are provided for recycling purposes:

  - Mandatory for all product (expect portable)
    - Printed Circuit Boards relating to computing functions >10 cm²
    - Stationary computer products Internal Power Supply Unit
    - HDD drives
  - Mandatory for portable product
    - Rechargeable battery
  - Optional:
    - HDD drive (for portable products)
    - Optical drives (where included)
    - Printed circuit boards ≤ 10 cm2 and > 5 cm2
    - Speaker units (notebooks, integrated desktops and portable all-in-one computers)
    - Polymethyl Methacrylate (PMMA) film light guide (where the screen size is >100 cm2).

- ***Mobile phones***

  The Blue Angel label for mobile phones targets the removable of battery for recycling purposes.

  The iFIXIT scoring scheme identified screen and batteries as critical components that should be easily replaceable for mobile phones.

<u>Ease of disassembly evaluation</u>

The ease of disassembly to facilitate repair, simple upgrade and/or refurbishment are key to enhance 'repairability' of products.

The European ecolabel for computers states that products should be designed to allow easy extraction of target components and parts. A short test procedure is described to evaluate the ease of disassembly. The number of steps including the associated tools and actions required to extract the target components and parts are documented during the test and are complemented by pictures and video material.

Different sources of difficulty in performing disassembly tasks have been identified and repairability criteria have been developed for the following items:

- ***Required tool type***

  The Blue Angel label includes the following related to tool type:
  - The removal of rechargeable batteries must be possible by using standard tools for recycling purposes. A guidance value of 5 seconds is provided.
  - It must be possible to dismantle the product manually by a specialist company with the aid of universal tools that are usually generally available in the retail trade. The dismantling process should be carried out by a single person.

  The Nordic Swan Label includes the following related to tool type:
  - The product must be easy to disassemble using common standard tools.
  - Connections are easily separable with generally available tools.
  - Target components should be removable without the use of special tools

  The European ecolabel includes the following related to tool type:
  - The extraction operations shall be performed using manual or power-driven standard commercially available tools (i.e. pliers, screw-drivers, cutters and hammers as defined by ISO 5742, ISO 1174, and ISO 15601).
  - The rechargeable battery must be extractable manually, depending on the product type (notebook, sub-notebook or tablet):
    - without tools;
    - in a maximum of three steps using a screwdriver;
    - in a maximum of four steps using a screwdriver and spudger
  - Products can be dismantled using universal tools (i.e. widely used commercially available tools such as a screwdriver, spatula, plier, or tweezers)

  The Austrian Technical Rules include the following related to tool type:
  - Important parts of the product should be removable (separated into individual parts) without special tools. If a special tool is required, it must be easily available for every repair shop (not only for those under contract with manufacturer)
  - Information is provided about special tool needed for repair

  The iFIXIT scoring scheme includes the following related to tool type:
  - The tool cost is reduced by using less than three different types of screws
  - Disassembling the product does not require a heating element

- ***Type and number of connections***

  The Nordic Swan Label includes the following related to type of connection:
  - Fixtures within the products shall allow for disassembly, e.g. screws, snap-fixes.
  - Metal inlays that cannot be separated are not used.

The European ecolabel includes the following related to type of connection:

  - Rechargeable batteries are not be glued or soldered into a product. Metal tape, adhesive strips or cables that prevent access in order to extract the battery are not used.
  - Depending on product type and target components, a maximum number of disassembly steps are given

The Austrian Technical Rules include the following related type of connection:

  - Releasability of connections which need to be opened during normal service life should be ensured
  - Use of commercially available screws and reducing their number are recommended to improve product repairability
  - Screw connections which cannot be released again should be avoided

The iFIXIT scoring scheme includes the following related to type of connection:

  - No proprietary screws or self-destructing fasteners are present
  - Use of fragile ribbon cables (that may easily tear) is minimized
  - Batteries are not glued with strong adhesive or soldered in place
  - Excessive amounts of adhesive are not used to secure internal components
  - Less than three different types of screws are used
  - The total number of screws is less than 30

- ***Amount of force required***

  The iFIXIT scoring scheme includes a criteria that states that the disassembling of the product should not require substantial prying effort.

- ***Use of standardized designs connections***

  Although the Blue Angel label only mentions the use of standard tool, this also implies that standard connectors are used. The Nordic Swan label specifically mentions that, where possible, connections are standardized. While the Austrian Technical Rules recommend the use of commercially available standard fasteners, the iFIXIT scoring scheme recommends to avoid the use proprietary screws.

- ***Modularity***

  The iFIXIT scoring scheme includes the following related to modularity:

  - Discretionary feel after having taken apart the product
  - LCD panel and display glass are two separate components (not fused together)
  - Internal components are modular, and are not grouped together on one cable

  The Austrian Technical Rules include a non-mandatory provision for the ability to break down the product into individual parts that are available as spare parts. The assessment should be carried out globally and not fix on details and the probability of a defective component is taken into account.

- ***Accessibility***

  Accessibility is defined as the ease with which a part can be accessed or reached by the tool or hand. The Blue Angel label states that the points of connection must be easily accessible in order to allow ease of disassembly. The Nordic Swan Label also mentions that connections are easy to locate and access. The European ecolabel establishes a number of target components that must be easily accessible. The iFIXIT scoring scheme states that components should not be tightly packed together, making disassembly easy.

- ***Required time***
  The Blue Angel label provides a guidance value for the efficient removal of the rechargeable batteries for recycling purposes of no more than 5 seconds. The iFIXIT scoring scheme rewards products that can be disassembled below the average assumed time (e.g. 30 mins for phone and 60 mins for a laptop).
- ***Required skills***
  The Blue Angel label mentions that dismantling of the products should be possible by one person. Furthermore, the European ecolabel for Notebooks requires the target components to be easy to extract by one person and specifies this can be either a non-professional user or a professional repair service provider. The European ecolabel also states that products should be able to be easily dismantled by professionally trained personnel.

In general, many of the included criteria mentioned above related to product design are subjective and not easily verifiable. To make it possible to include repairability criteria in policy requirements and to grade product based on their repairability in an Ecodesign context, an unamigiuous easily verifiable metric is required that takes all prior mentioned aspects into account. Since the eDIM method takes most of the prior mentioned product design related aspects into consideration including: tool type, number and type of connection and accessibility, the use of eDIM to assess the ease of repair is proposed. However, the modularity is not fully taken into account in the eDIM method, as a modular product can reduce the number of disassembly steps required for partial disassembly targeting a specific component, but when components cannot be disassembled from each other the ease of disassembly cannot be calculated. In addition, limitation on the required skills are not included in the eDIM method, as the eDIM method assumes the availability of perfect information and disregards the time that could be spend on unsuccessful attempts due to imperfect product information or knowledge.

- **Requirements on provision of services**

<u>**Availability of spare parts**</u>

The repairability of products is often constrained by the unavailability of spare parts for critical components. Therefore, the availability of replacement parts is required for a certain period of time after the last component batch production. The length included in the different criteria vary and depend on the product group. Typically 5 years is proposed for brown goods and 10 years for white goods.

The Blue Angel label requires the applicant to ensure and undertake spare parts supply during a specified time period after the production ceases. The time period for spare part availability depends on product type, for instance:

- 10 years for refrigerators, freezers and washing machine;
- 8 years for vacuum cleaners ;
- 5 year for computers, video conference products, coffee machines and TVs; and
- 3 years for Set-Top-Boxes.

The Nordic Swan label states the availability of spare parts must be guaranteed for at least 10 years (white goods) or 5 years (brown goods) after production.

The European eco-label for computers includes requirements for the applicant to ensure that a supply of original or backwardly compatible spare parts and necessary infrastructure for equipment repair is public available for a period of at least 5 years after the end of production of a given model. The European ecolabel also requires that users are informed about the guaranteed availability of spare parts. The European ecolabel allow for an exception in case of unavoidable and temporary circumstances that are beyond manufacturer's control such as a natural disaster.

According to the Austrian Technical Rules, a reference list of spare parts providers (address of customer service) must be available and the supply of spare parts should be ensured for at least 10 year for white goods and 5 years for brown goods after ceasing production

iFIXIT criteria do not specifically mention the availability of spare part although it is implied by other's such as 'ability to easily replace critical components' which obviously assumes spare part are available.

Unfortunately none of the reviewed criteria include specification on the cost of spare part.

Extension of warranty/guarantee period

Currently, under the Consumer Rights Directive (2011/83/EC), the final seller is liable for a product during a period of 2 years. However, the burden of proof that there was a defect or weak component at the time of the purchase lies with the consumer after the first 6 months.

The Nordic Swan label and European ecolabel require an additional year of warranty without additional cost for the consumer. For the Nordic Swan label, the warranty that the product will work applies from the day that the machine is delivered to the customer, while for the European ecolabel the commercial guarantee is effective from the purchase of the product. This guarantee includes a service agreement with a pick-up and return option for the consumer. This guarantee must be provided without prejudice to the legal obligations of the manufacturer and seller under national law.

The Austrian Technical Rules require that the average lifetime for white goods must be at least 10 years and 5 years for brown goods. This information will be provided in a label which will be available to consumers.

Take back systems

The Blue Angel labelling requirements for mobile phones require the applicant to operate its own take-back scheme for mobile phones to direct all collected products to proper treatment (reuse, recovery and/or recycling). The applicant must actively communicate this system to its customers. This take-back scheme can be based on collections at the branches, return campaigns, deposit systems or similar.

The Nordic Swan label scheme requires the user instructions to include information on how the consumer can take advantage of the manufacturer's take-back scheme.

The European ecolabel mentions take-back schemes as a possible end-of-life option and if available then this information should be included in the user manual. The European ecolabel for imaging equipment specifically requires a take back scheme to be set up by the applicant for toner and/or ink containers supplied or recommended by the applicant for use in the product. The returned modules and containers must be reused as much as possible. If reuse is not possible, the material should be recovered and recycled. Modules and containers shall be taken back free of charge by the return facility named by the applicant. The product documents must include detailed information on the return system.

Chapter 4: Developed methodology for repairability evaluation

4.1 Repairability assessment method

A structured approach is taken to develop a set of generic repairability criteria for ErPs. For each repair steps (see *Figure 5*), the challenges of the related activities are listed. Relevant criteria to address those challenges are proposed and grouped in three categories, defined as follows:

- Criteria that require information, such as failure diagnostic guides or disassembly instructions, to be provided;
- Criteria that are related to the product design, such as ease of disassembly; and
- Criteria that are related to services, such as technical support or spare parts supply, that can be provided by the manufacturer.

This resulted in the matrix shown in *Figure 7*. The developed repairability criteria are outlined in the subsequent sections of this chapter. The repairability criteria are individually rated based on the selected option (see *Figures 8 to 12*). For each criterion a set of options are provided. The option that will increase the likelihood of a successful repair receives the highest score. This set of criteria is not developed for a specific product group. Therefore, specific parts of the criteria, that are subject to be revised and potentially adapted to obtain criteria for specific product groups, are highlighted with asterisks (*). The assigned scores for the different options of a criterion could also be subject to product group specific changes. This will influence the weight and contribution of the criterion to the total repairability score.

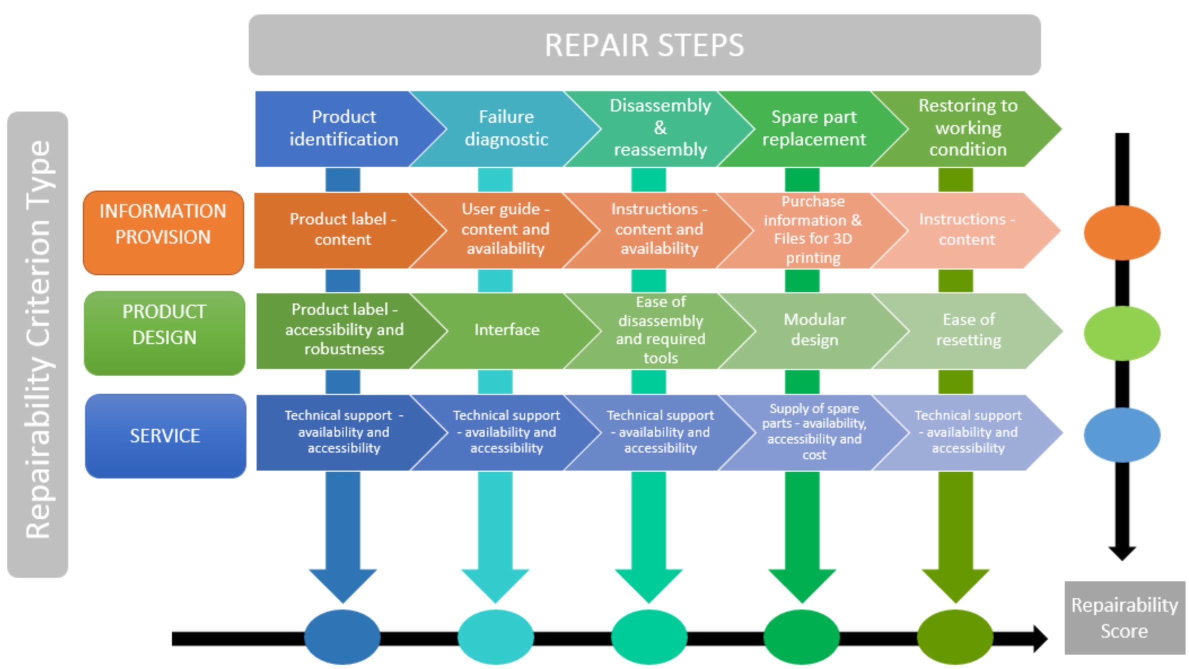
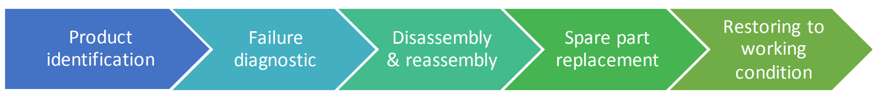


Figure 7: Repairability assessment methodology - overview

The maximum achievable scores for each part of the assessment are provided in *Figure 8*. This shows the relative importance given to each repair step and to the different criteria type group. For example, less weight is given to the final repair step, “restoring to working condition”, as in most cases this will not be the bottleneck for repair. However, if for a specific product type this would be the case, the scoring and criteria weights can be adapted accordingly. In the current proposed method, step 4, replacement of spare part, and step 3, disassembly and reassembly, contribute slightly more to the overall repairability score compared to other repair steps. For the service provided by the manufacturer during the use of the sold product, the provision of spare parts has been given more weight as this has been identified as an important issue by the different consulted stakeholders during this study. However, overall the weights for the generic assessment tool have been quite evenly distributed, with some more emphasis on product design (38% of total score), compared to information provision (29%) and service (34%).



	Maximum scores					
	Step 1	Step 2	Step 3	Step 4	Step 5	
Information Provision	10	10	10	12	5	47
Product Design	15	10	20	15	2	62
Service	10	10	10	20	5	55
	35	30	40	47	12	164

Figure 8: Repairability assessment methodology – maximum scores

Depending on the repair route, in house, professional repairer or self-repair, different challenges will need to be overcome and this must be taken into account when assessing the repairability of products. A manufacturer can provide different content to different target groups such as professional repairers or consumers. The reparability assessment should be done from a specific perspective and can results in different scoring depending on the considered target group. It should also be noted that not all professional repairers may have access to the same information. Some professional repairer may be required to follow specific trainings before receiving more detailed repair information and in other cases information is only shared when the professional repairer is working under service contract for the manufacturer.

In the case studies, explained in subsequent chapters of this report, two perspectives have been taken into account. Both perspectives of a professional repairer and an end-user or consumer are considered. In this research the criteria and their respective weights are not adapted for the considered perspective.

In a next step of the method development, more emphasis could be given to specific criteria that are more relevant for the considered perspective. The weights of an individual criterion or a group of criteria can be adapted by increasing or lowering the maximum achievable score. For a professional repairer, the product design could be more important while for a consumer the available information and access to adequate repair service can be decisive for the feasibility of repair.

Some criteria can be assessed at product level (e.g. product identification), but other criteria might need to be assessed for each identified priority part (e.g. availability of spare parts). Before the start of the repairability assessment a list of priority parts should be compiled, if not already available for the relevant product group. Priority parts should not take into account current difficulties to be replaced or repaired, hence the priority list should only take the following into account:

- Most frequent failure modes or misuses of products
- Parts that are most likely to be replaced or repaired during the lifetime of a given product group
- Functional criticality

When criteria related to the repairability assessment are dependent on the targeted priority parts, several options can be envisaged to aggregate the score. A first option is to calculate the average which would give each priority part the same importance or weight in the total score. Another approach is to only considered the priority part with the worst score which results in a weakest link approach. Finally, if failure rates are provided, more weight can be given to parts that are more likely to be replaced. In this third approach, the calculation for the weighted average should be transparent and clearly documented. In the cases studies explained in subsequent chapters this third approach is applied in order to account for the relevance of the different priority parts.

Further details on the calculation method can be found in the excel spread sheet accompanying this report.

4.2 Repairability criteria related to product identification

Product identification is useful to look up relevant repair documentation or identify compatible spare parts required to repair products. Furthermore, in the case of large scale independent repair automated identification is important to achieve a high(er) throughput. In some cases identifying the product model can be rather trivial as the product model is printed/engraved on the product housing. However, the label is often not machine readable. *Figure 9* summarizes the criteria developed for this repair step.

Items that could be adapted depending on the product group are: (1) font size used on labels, (2) number of connection to remove prior to accessing label and (3) number of years the service from manufacturer to support product identification remains available.

Additionally the maximum score assigned to each option can be adapted for a specific product group. In the current proposed method, all criteria refer to a fixed set of maximum score given in the top row of *Figure 9*. However, as mentioned in previous section, in future development of the tool a separate set of maximum scores can be proposed for every criterion in order to adapt the weight of each criterion in the total repairability score. Alternatively a mathematical function could be proposed. For example, the score for the duration of availability of identification support (criterion 1.4) could be expressed as the ratio of the duration divided by a reference value.

Repair Step 1: Product identification					
Nr	Criterion description	0	2	5	10
1.1	Ease of identification	Not available		Brand and unique model version reference at least point 10*	Brand and unique model version reference at least point 10* and GTIN code integrated in black/white barcode or QR code
1.2	Accessibility of identification	Not available		Accessible only after removal of less than 2* connections	Accessible after manual operation without disconnecting components
1.3	Robustness of identification	Not available	All or part of the product identification information is included on removable labels e.g. glued	All product identification information is engraved or printed	
1.4	Availability of identification support	Not available	Technical support from manufacturer available for product identification for at least 5* years after last production	Technical support from manufacturer available for product identification for at least 10* years after last production	
1.5	Accessibility of identification support	Not available	Local fee contact available for product identification.	Toll-free or web-based support available for product identification.	

Figure 9: Repairability criteria related to Step 1 product identification (see overview on Figure 6)

- **Information provision**

Information for product identification can be provided in many ways. The non-profit organisation GS1 develops and maintains global standards for business communications, such as the Global Trade Identification Number (GTIN), in close collaboration with ISO. The GTIN is a collection of data structures deployed globally, such as the European Article Number (EAN), the Universal Product Code (UPC) and Uniform Commercial Code (UCC) data structures.

The GTIN data structures are incorporated in the GS1 barcode family, enabling identification of unique trade items, products and services, and in a robust manner with a check digit system included for correct identification. The GS1 barcode family includes 1D, 2D and QR codes.

The availability of machine readable labels, such as barcodes and QR codes, encompasses many advantages for both repair operations and automated sorting systems, as it allows faster and more robust identification. Therefore, a higher score can be achieved when such a label is present on the product. The packaging of the product is not included in the repairability assessment as this is assumed to be thrown away within the first year of use.

- **Product features and design**

Most products are labelled, however the labels are not always directly visible or easily accessible. If the label is only readable after the removal of connections, this will increase the required time and also hamper automated identification and sorting of (failed) products.

The way the label is put on the product will influence the likelihood of the label remaining on the product during its entire useful lifetime. The most robust labelling is achieved by engraving or printing on the product. Removable labels such as glued labels are considered to be less reliable.

- **Service provided**

If the product model cannot directly be identified from the product, the manufacturer may provide support to help repair professionals or customers to identify their specific product model. This will most likely be a time consuming task as the interaction will most likely be over the phone and the identification will be based on the description of some product features. However, if the manufacturer has a dedicated service to support product identification, this can be seen as an alternative solution. Points are awarded depending on the period that such a service is provided. Additionally, the accessibility is assumed to increase as the fee for such a service is reduced.

It should be noted that indirect product identification through technical support, will in many cases be substantially more time consuming than direct product identification for example through labels and should, therefore, only be rewarded for specific products and/or in specific business models.

4.3 Repairability criteria related to failure diagnostic

Failure diagnostics and problem identification is key for an efficient and effective repair procedure. For the purpose of this study, limited aesthetic damage is not considered as in this case the product is still in sufficient working condition to fulfills the main function. A challenge to identify the problem, is that it often requires partial disassembly. The specific issues related to ease of disassembly are covered separately in the next section while the criteria discussed in this chapter focus on the problem identification itself.

In some cases the required repair actions are easily identified and no further testing is required. This can be related to the type of failure (e.g. disconnected wire, obstruction in pipe or dirty filter) or because of the product design providing a visual signal for failure identification and clear pictogram or instructions on product for required repair.

However, in many cases identifying the problem, failed component and required actions can be a time consuming step , especially when performed without any guidance. Additionally error codes are used to inform the user about the failure mode, but the translation of the encrypted error codes are often not publicly available. However, this may not be a barrier for in-house repair as detailed service documents are available for them including step by step guidance for each error code. *Figure 10* summarizes the criteria developed for this repair step.

Items that could be adapted depending on the product group are: (1) specific common failures identified for a specific product group, (2) key functional parts and (3) number of years the service from manufacturer to support failure diagnostic remains available.

Additionally the maximum score assigned to each option can be adapted for a specific product group in order to change the weight of each criterion in the total repairability score. Alternatively a mathematical function could be proposed.

Repair Step 2: Failure diagnostic					
Nr	Criterion description	0	2	5	10
2.1	Instructions for problem identification - content	Not available	Repair instructions include the following elements: - safety measures - (check)list of identified root causes for common failures/misuses	Repair instruction includes the following elements: - safety measures - basic fault diagnostic advice: (check)list of identified root causes for common failures* - test method to check working condition of key functional parts* - limited list of error codes and required repair actions, if applicable	Repair instruction includes the following elements: - safety measures - fault diagnostic advice: (check)list of identified root causes for common failures* and troubleshooting tree - test method to check working condition of priority part - complete list of error codes and required repair actions, if applicable - diagrams of the Printed Circuit Board, if applicable - fault detection software , if applicable
2.2	Product designed for easy failure detection	Not available	Fault detection software and a separate PC (or alike) are required to proceed to failure detection	Coded interface: Cause of failure can be established by means of the control panel/display. Supporting documentation (e.g. error codes) could be required.	Visually intuitive interface: Cause of failure can easily be established due to implemented features in the product (software) design. There is no need for additional supporting documentation or software
2.3	Availability of failure diagnostic support	Not available	Technical support from manufacturer available for failure diagnostic for 5* years after last production	Technical support from manufacturer available for failure diagnostic for at least 10* years after last production	
2.4	Accessibility of failure diagnostic support	Not available	Local fee contact available for failure diagnostic.	Toll-free or web-based contact available for failure diagnostic allowing customer to identify issues and required repair actions	

Figure 10: Repairability criteria related to Step 2 failure diagnostic (see overview on Figure 6)

- **Information provision**

Product specific instructions for problem identification and cause analysis procedures provided by the manufacturer can reduce the required time for failure diagnostic. Concerning the description of the diagnostic procedures, it is important that these instructions are unambiguous for end-users and that they include the necessary safety precautions, checklists and troubleshooting trees, ensuring a smooth process. For the purpose of the repairability assessment, it is assumed that repair becomes easier as more information is available

A manufacturer can provide different content to different target groups such as professional repairers or consumers. The repairability assessment should be done from a specific perspective and can result in different scoring depending on the considered stakeholder group. It should also be noted that not all professional repairers may have access to the same information. Some professional repairers may be required to follow specific trainings before receiving more detailed repair information while in other cases information is only shared when the professional repairer is working under service contract for the manufacturer.

- **Product features and design**

Implementing an integrated system for failure detection of components in the design of the product itself can ensure the ease of identifying the causes of failures. This can be made prominent in a visually intuitive interface with clear indications or dedicated supporting information (e.g. a trouble shooting tree). Coded indications can be used as well, on the condition that the details of the coded indications are properly documented and easily accessible.

- **Service provided**

A manufacturer can provide failure diagnostic support, or choose to collaborate with subcontractors or third parties to deliver this service. Such a technical support service should allow to identify the main failure of the product and help to obtain some further insight on feasibility and cost of potential required repair steps. To improve the accessibility of this service, associated fee or cost should be reduced.

4.4 Repairability criteria related to disassembly and reassembly

The disassembly and subsequent reassembly are a key step in the repair cycle both to fix failed parts or to replace them. *Figure 11* summarizes the criteria developed for this repair step.

Items that could be adapted depending on the product group are: (1) size and level of details in exploded diagram, (2) eDIM reference value for partial or complete disassembly and reassembly, (4) assumed available tools and (3) number of years the service from manufacturer to support disassembly and reassembly remains available.

Additionally the maximum score assigned to each option can be adapted for a specific product group in order to change the weight of each criterion in the total repairability score. Alternatively a mathematical function could be proposed. For example, the score for the ease of disassembly (criterion 3.2) could be expressed as the ratio of the weighted partial eDiM divided by a reference value.

Repair Step 3: Disassembly and reassembly		0	2	5	10
3.1	Disassembly instructions - content	Not available	Disassembly instructions include the following elements: - exploded diagram (include minimum size*)	Disassembly instructions include the following elements: - exploded diagram (include minimum size*) - list of required tools - list of connectors used	Disassembly instructions include the following elements: - exploded diagram (include minimum size*) - list of connectors used - list of required tools - description of recommended disassembly steps to remove priority parts*
3.2	Product designed for ease of disassembly	Product cannot be disassembled and reassembled	Reduced ease of disassembly: >10% slower than an reference value* for complete* product disassembly OR Reduced ease of disassembly: average eDIM for partial disassembly represents >30% of eDIM for total disassembly	Average ease of disassembly: does not deviate more than 10% of reference value* for complete* product disassembly OR Average ease of disassembly: average eDIM for partial disassembly represents between [15%-30%] of eDIM for total disassembly	Increased ease of disassembly: >10% faster than an reference value* for complete* product disassembly OR Increased ease of disassembly: average eDIM for partial disassembly represents <15% of eDIM for total disassembly
3.3	Required tools for disassembly	Not available	Priority part(s) can be replaced using specialized commercially available tools (from specific list Annex B*)	Priority part(s) can be replaced using only common general purpose tools (from specific list Annex A*)	Priority part(s) can be replaced with one tool*
3.4	Availability of technical support for disassembly and reassembly	Not available	Technical support from manufacturer available for disassembly and reassembly for at least 5* years after last production	Technical support from manufacturer available for disassembly and reassembly for at least 10* years after last production	
3.5	Accessibility of technical support for disassembly and reassembly	Not available	Local fee contact available for disassembly and reassembly.	Toll-free or web-based contact available for disassembly and reassembly allowing customer to access and repair / replace failed part through assisted disassembly and reassembly.	

Figure 11: Repairability criteria related to Step 3 disassembly and reassembly (see overview on Figure 6)

- **Information provision**

To support a reversible and non-destructive repair procedure, unambiguous disassembly instructions should be provided by the manufacturer. Disassembly procedures could contain a step by step instruction manual, indicating the necessary tools for each action and a description of the type of connections used, complemented by images of the product or exploded view diagrams with indicators of the position of the different types of connections. A separate list of required tools can be provided which can be consulted before starting the disassembly procedure.

oManual has developed a manual format, which has been incorporated in the IEEE standard: IEEE 1874 (24). This standard describes the format for documentation schemas and guides for disassembly in an XML structure, complemented with an Application Programming Interface (API) to exploit this format in IT applications. However the standard does not specify minimum content requirements, which should be further developed.

- **Product features and design**

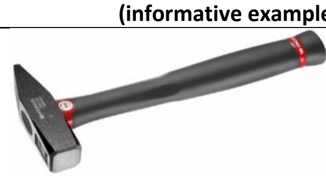
Product design has a significant role in disassembly and re-assembly activities. Therefore, the design of the product should facilitate the ease of disassembly. This can reduce the time and, accordingly, the cost associated with repair activities significantly.

As described in earlier section 3.4, a method to evaluate the ease of disassembly of products has been developed by KU Leuven in collaboration with JRC. The method calculates the "ease of Disassembly Metric" (eDiM) and aims at assessing the effort needed to completely or partially disassemble a product. The eDIM can be calculated for total product disassembly or for partial disassembly of targeted priority parts. Additionally the repairability criterion related to the eDIM can be defined relative to a defined reference value for a specific product group or the partial disassembly of a specific single product can be compared to the total disassembly of that same product. In the latter case the assessment results should not be used for comparison to other products.

Tool-less disassembly procedures are assumed to allow for the fastest disassembly. However, when this cannot be avoided, design for standardised or generic tools are preferred as these are commonly available. Additional time to source non-standardized tools can also be included in the eDIM calculations (22,23). For the purpose of this study, to simplify the use of the eDIM method, it is easier to take into account the additional time, cost and difficulty of sourcing non-standardized tools in a separate criterion (see 3.3 in *Figure 11*). Two lists of commercially available tools and their reference standards have been proposed in this study for the development of such a tool-related criterion. Both tool lists are given in the tables below and are partially based on the prEN45554 draft standard on reparability.

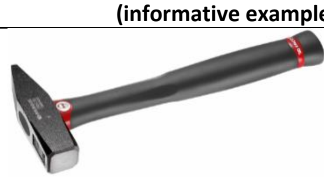
Both tool lists A and B represents the tools most commonly used for repair purposes in general, regardless of the specific product being repaired. As a means of identifying the lowest possible threshold for those processes which cannot be performed without the use of any tools, tool list A contains a very limited number of tools which are hand operated, widely used commonly available by households and which readily available for purchase by any individual or business without restrictions. Tool list B is an extended list with some additional tools or tool sizes. The tools are still commercially available without restrictions but might not be present in most households. However, they may be present in small scale (repair) workshop.

Table 5: Tool list A

Tool type	Illustration (informative example)	Reference
Hammer, steel head		ISO15601
Half-round nose pliers		ISO5745

Combination pliers (clamping and cutting)		ISO5746
Diagonal cutters		ISO5749
Hexagon socket keys (Allen keys) **Size 2, 2.5, 3, 4, 5, 6**		ISO2936
Screwdriver for slotted heads **Size 3x100/190 mm, 5x100/195 mm**		ISO2380
Screwdrivers for cross-recessed Phillips® heads **Size PH-0x75/165 mm ; PH-2x100/205 mm**		ISO8764
Utility knife (cutter) with snap-off blades		

Table 6: Tool list B

Tool type	**Illustration (informative example)**	**Reference**
Hammer, steel head		ISO15601
Combination pliers (clamping and cutting)		ISO5746
Half-round nose pliers		ISO5745
Multigrip pliers (multiple slip joint pliers)		ISO8976
Diagonal cutters		ISO5749
Combination pliers for wire stripping & terminal crimping		

Combination wrench **Size:8,10,12,13,15,17,19,20,22**		ISO7738
Hexagon socket keys (Allen keys) **Size 1.5, 2, 2.5, 3, 4, 5, 5.5, 6, 7, 8, 10**		ISO2936
Screwdriver for slotted heads **Size 3x100/190 mm, 4x100/190 mm 5x100/195 mm 6x100/195 mm 7x100/195 mm**		ISO2380
Screwdrivers for cross-recessed **Phillips® Size: PH-0x75/165 mm; PH-1x75/165 mm; PH-2x100/205 mm; PH-3x100/205 mm** **Pozidriv® Size: PZ1 , PZ2**		ISO8764
Screwdrivers for hexalobular recess **Torx® heads size T2 T3 T4 T5 T6 T7 T8 T9 T10 T15**		ISO10664 (driving feature)
Multimeter		
Utility knife (cutter) with snap-off blades		

- **Service provided**

A manufacturer can provide disassembly and reassembly support, or choose to collaborate with subcontractors or third parties to deliver this service. Such a technical support service should allow to guide a repair operator though specific disassembly steps when required. To improve the accessibility of this service, associated fee or cost should be reduced.

4.5 Repairability criteria related to spare parts

In many cases the repair procedure will include replacing one or more components for which a spare part needs to be available within a reasonable amount of time and for a reasonable price.

Figure 12 summarizes the criteria developed for this repair step.

Items that could be adapted depending on the product group are: (1) priority parts, (2) % by count of available spare parts for priority parts, (4) relative average cost of spare parts compare to catalogue price and (3) number of years supply of spare parts from manufacturer remains available.

Additionally the maximum score assigned to each option can be adapted for a specific product group in order to change the weight of each criterion in the total repairability score. Alternatively a mathematical function could be proposed. For example, the score for the content of supplied spare parts (criterion 4.5) can be expressed as the ratio of the number of spare parts provided divided by the total number of spare parts.

Nr	Criterion description	0	2	5	10
4.1	Information for spare parts	Not available		Information related to spare parts include the following elements: - Information on spare parts supply (address , webshop)	Information related to spare parts include the following elements: - Information on spare parts supply (address , webshop) - Spare part register including unique reference numbers of available spare parts
4.2	Information for 3D printing of spare parts	Not available	Information to allow customer to print spare part is available when relevant (for "simple" parts such as switches or product casing)		
4.3	Modular design of the product	Not available	At least 50% (by count) priority parts* can be replaced individually	At least 75% (by count) priority parts* can be replaced individually	All priority parts* can be replaced individually
4.4	Standardized design	Not available	A number of priority parts* are standardized	All priority parts* are standardized	
4.5	Supply of spare parts - content	Not available	Compatible spare parts for priority parts* are limited available for this product 50%* (by count)	Compatible spare parts for priority parts* are widely available for this product 100% * (by count)	
4.6	Supply of spare parts - availability	Not available	Mid-term availability of spare parts availability for at least 5* years after last production	Long-term availability of spare parts for at least 10* years after last production	
4.7	Supply of spare parts - cost	Not available	Average consumer price of available spare parts is between 10% and 20%* of catalogue price of the product (20% included)	Average consumer price of available parts is between 5 and 10%* of catalogue price (10% included)	Average consumer price of available parts is less or equal to 5%* of catalogue price

Figure 12: Repairability criteria related to Step 4 Spare parts (see overview on Figure 6)

- **Information provision**

Maintaining and providing a detailed overview of available spare parts further facilitates the repair process as the time to identify, locate and purchase the spare parts can be reduced significantly. In the best case the information provided by the manufacturer allows to identify the required spare parts through a unique reference number and to purchase it, for example through a web shop. Availability from third parties is not considered for this assessment as the manufacturer cannot guarantee the availability and quality of this supply.

Additionally, manufacturers can provide the necessary information to enable 3D printing which can further facilitate the ease of acquiring spare parts, especially for products no longer in production. It should be noted that this option is only applicable to “simple” parts.

- **Product features and design**

Even though combining parts in a (sub)assembly can provide advantages related to partial disassembly time for priority parts that are located at increased depth within, it is import that the ability to replace individual priority parts is not sacrificed.

The product design should allow for individual priority part replacement using standard components to ensure a smooth replacement of failed parts.

- **Service provided**

In the proposed generic criteria, only the priority parts are considered for the assessment of spare parts. The criteria cover the content (which spare parts are available?), the availability (for how long?) and the cost (compare to the catalogue price of the product) of the spare parts.

In terms of availability, providing a long term supply of spare parts ensures the feasibility of repair throughout the use of the products. This also increases the likelihood of consumers to invest in such (long-term) repairable products.

The pricing of spare parts are preferred to be as attractive as possible for consumers in order to increase the likelihood of repair. Even though the retail price may differ from the standard new purchase price and can also vary in time, this is decided by the retailer and not the manufacturer. Therefore the cost of priority parts are compared to catalogue prices as proposed or advised by manufacturers.

If the availability and cost of spare parts varies in time, an average over time can be taken. If the failure rate is provided, more weight can be given to parts that are more likely to be replaced. In that case the calculation for the weighted average should be transparent and clearly documented.

4.6 Repairability criteria related to resetting to working condition

Although resetting to working condition may not require additional handling for all products, in some specific cases it can be key. In some specific cases for example the error code cannot be removed unless the product is connect to specific software or a specific combination of buttons is pressed. As this may represent a barrier is some cases for the repair of products, a number of criteria are defined. *Figure 13* summarizes the criteria developed for this repair step.

Items that could be adapted depending in product group are the number of years technical support or reconditioning from manufacturer remains available.

Additionally the maximum score assigned to each option can be adapted for a specific product group in order to change the weight of each criterion in the total repairability score. Alternatively a mathematical function could be proposed.

Nr	Criterion description	0	2	5	10	Score
5.1	Instructions for reconditioning of product	Not available		Repair instruction includes procedure to reset to default / factory settings and restore product to working condition, as appropriate.		0
5.2	Product designed for ease of restoring to working condition after repair	Not available	Product resetting can be done without intervention with an external / specialized device			0
5.3	Technical support for reconditioning - accessibility	Not available	Local fee contact available for reconditioning.	Toll-free or web-based contact available for reconditioning.		0

Figure 13: Repairability criteria related to Step 5 Resetting to working condition (see overview on Figure 6)

- **Information provision**

Repair instructions for resetting the product to working condition should be included as appropriate and can include procedures to reset the products to default settings or factory conditions. This may be required after performing intrusive repair operation or this can resolve malfunctioning by itself. However factory reset strategies should remain a last resort when failure identification was not possible because hardware problems might still persist afterwards.

- **Product features and design**

It is assumed that repair will be easier when the resetting can be done without intervention with an external or specialized device. For example, a dedicated factory reset function or button in the design can ensure a smooth procedure of resetting the product to factory working conditions.

- **Service provided**

A manufacturer can provide technical support for reconditioning, or choose to collaborate with subcontractors or third parties to deliver this service. Such a technical support service should guide the users to reset their repaired products to working condition as required. To improve the accessibility of the service, toll free or regional contact details at local fee are preferred.

Chapter 5: Case Study 1: Washing Machines

5.1 Definition and characterization of selected product group

- ***Definition and functionality***

Household washing machines are widely present in European households, with an average household ownership rate of about 92% and 17,2 million new household washing machines sold in 2015 (25).

An updated definition of 'Household washing machine' has been proposed during the revision process of the eco-design directive as '*an automatic washing machine which cleans and rinses textiles using water, chemical, mechanical and thermal means which also has a spin extraction function and which is designed to be used principally for non-professional purposes*'(26).

During the preparatory work for the eco-design update, the following primary and secondary functions of the washing machines were identified during the stakeholder consultation (26):

- Primary functions
  - washing / cleaning;
  - rinsing;
  - spin extraction
- Secondary functions:
  - automatic detergent dosage
  - possibility of adapting the spin speed
  - capability to be remotely controlled (Demand Response functionality)

Each washing machine model has their specific set of available washing programs adapted to certain textile types that typically vary in temperature, wash time, spinning speed, water use and load capacity. The results of a semi-representative online survey, conducted by Alborzi et al, show a clear dominance (62%) of the cotton wash program over all other washing programs (27).

Washing machines can also be provided with safety controls and detection systems against water leaks or unbalanced loads (28).

- ***Technology: different designs and engineering solutions***

Today, there is a wide variety of washing machines configurations available on the market. While the top-loading washing machine has the largest market share in the United States, the front-loading washing machine is the dominant design in Europe (29) and therefore the focus of the present study.

Front-loading washing machines have been found to have highest energy and water use efficiency (30). However the actual resource consumption during the use phase of the washing machine highly depends on the consumer behavior (31) such as frequency of washings, wash temperature and filling load.

- ***Capacity and performance***

The base load capacity of washing machines has gradually increased over the last 2 decades. The average base load for cotton laundry of washing machine types sold in Europe increased from 4,8 kg in 1998 to 7 kg in 2013 (26). Currently, available capacity of washing machine on the market range from 5 to 10 kg.

The energy standards and labels on washing machines facilitated the development of water- and energy-efficient washing machines (29). The energy efficiency classes of washing machine models available on the EU market have constantly evolved over the past two decades as shown in *Figure 14*. The average declared energy consumption of standard programmes was reduced by half from 0,245 kWh per kg and cycle in 1997, to 0,120 kWh per kg and cycle in 2013 (26). Although the EU Energy Label class has been extended several times, most product models on the market achieve the highest class A+++. However, the water and energy optimised programmes designed to achieve a high energy-labelling class are not always used by consumers (27).

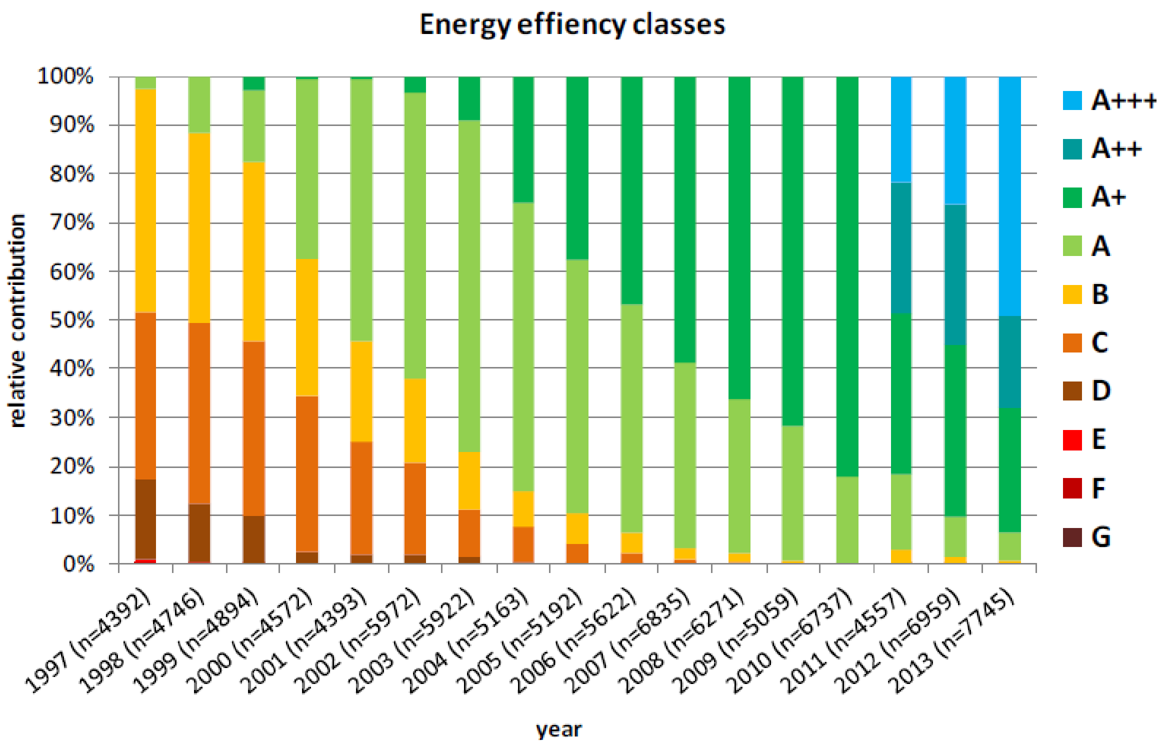


Figure 14: Distribution of energy efficiency classes for washing machines in 1997-2013 (CECED 2014) (26)

Over the last years, the average spin speed per cycle has steadily increased from 828 rpm in 1997 up to 1219 rpm in 2010 (26). The proportion of machines with maximum spin speeds of less than 1000 rpm has decreased over the last decade, and the market share is negligible for maximum spin speeds in excess of 1600 rpm. Spin-drying is an energy-consuming function and the spin-drying efficiency is part of the information displayed on the label of the washing machine. According to the CECED (2014) database, in 2013 around 56% of washing machine models fell into spin drying class B.

Between 1997 and 2005, the average water consumption of washing machines per cycle has significantly declined, but has stabilized since then (26). However, water consumption per kg of rated capacity has steadily decreased as the base load capacity has increased. In addition, the eco-design regulation for WM implemented in 2010 defines a water consumption limit that depends on the rated capacity. According to the Belgian consumer organisation Test Aankoop, the reduced water use during the wash cycle is compensated by some users with additional rinsing cycles which could lead to overall higher water consumption (28).

- ***Average product/components lifetime***

The assumed average technical lifetime has decreased from 15 years, which was a common assumption in literature until 2009 (29,32,33), to 12,5 years which has been used in most recent EU studies (26,34,35). A negative trend of median lifespan for washing machine between 1995 and 2005 from 12,1 to 11,7 years was also confirmed by (36).

From the given Weibull distribution in previous research, a constant failure rate (average) of 7,2% can be deduced for 2005 (36).

Previous lifetime studies conducted by Stiftung Warentest on washing machines over timeline 2000-2014 were summarized in previous research (34,37). The 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. From this a average failure rate during the first 10 year of 6,8% could be deduced.

- ***Overview of possible failures and upgrades of the selected product group***

In 2015 the Belgian consumer organization "Test Aankoop" has analyzed the results of a large scale European survey with almost 35 500 users regarding the reliability of their home appliances (38). The frequent failures reported in the survey are shown in *Table 7*. It should be noted that for the failure 'Water circulation' cited in *Table 7*, the following reported failures modes from the consumer survey are summed up: 'drain pump', 'filters' and 'water leaks'.

RREUSE, an organization that represents social enterprises active in reuse, repair and recycling, has also carried out a survey in 2013 among their members (39). The report lists a number of frequent failures but no occurrence rate is provided.

In 2011, WRAP (*Waste and Resources Action Programme*) has also looked into the durability and repair of washing machines (40). This included some research with washing machine manufacturers and the repair industry to identify parts that are more prone to wear and that are more likely to need replacing.

Tecchio et al. conducted an elaborate analysis of durability, reusability and repairability of washing machines (34). The research indicated that for only a limited number of cases the problem was not identified (1,2%). Frequent failures were identified from a database containing 6672 reports of failure diagnostic and repair operations for in-use washing machines. The repair services were provided and reported between 2009 and 2015 by a repair center located in Vienna. In 29.7% of the 6672 cases for which a failure mode was identified, a combined failure was observed, meaning that two or more defective components or failure modes were identified. This resulted in a total of 9492 identified failure modes. The observed occurrence of the different failure mode is shown in *Figure 15*. The collected data indicates that combined failures are more difficult to successfully repair. For the cases where only one defective component or failure mode is identified, the success rate for repair was observed to be 85%. On average, for both single and combined failures, 76,7% of the cases were successfully repaired (5106 cases out of 6672).

Table 7: Failure modes occurrence rate of WM based on repair service report and/or consumer surveys (34,38–40)

	Tecchio et al (2016)	Test aankoop (2015)	RREUSE (2013)	WRAP (2011)
Water circulation	19%	29,60%	X	X
Motor	18%	5,50%		X
Washing Unit	16%	11%	X	X
Electronic	14%	5,5%	X	X
Door	11%	11,8%	X	X
Foreign objects	6%			
Switches	4%	8%		
Heater & thermostats	3%		X	X
Pressure chamber	2%			
Detergent drawer/hose	2%	8,80%		X
Cables/plugs	2%			
Corrosion		7,6%		

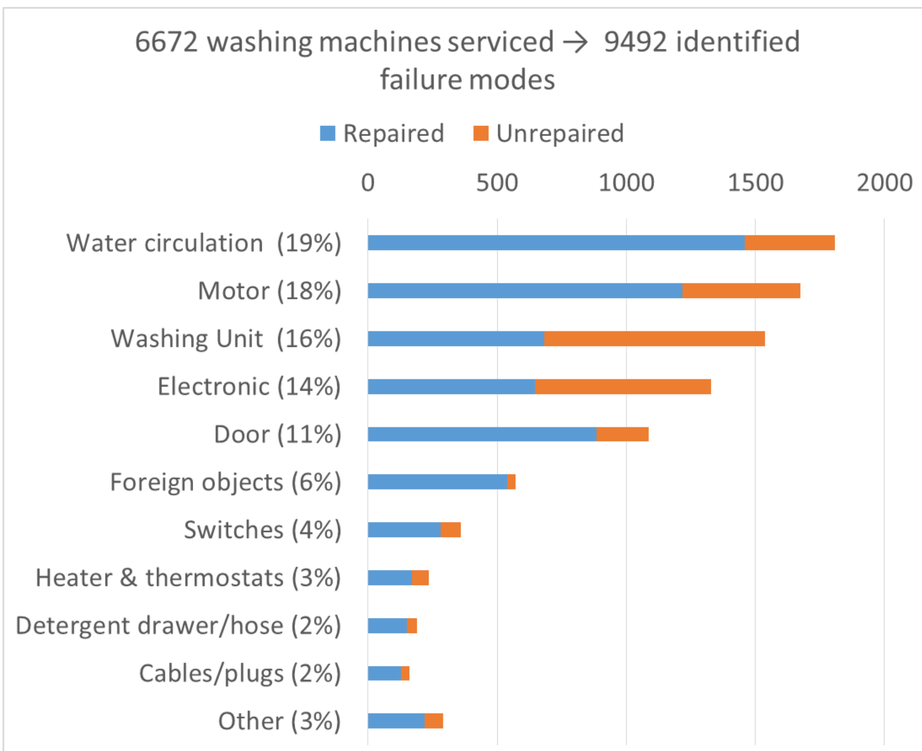


Figure 15: Identified failure modes for 6672 serviced washing machines and 9492 failure modes – modified from (34)

According to the data analyzed by Tecchio et al, the decision not to repair the washing machine is mostly taken by the consumer based on economic considerations and taking into account the age of washing machine (78%). Only in 22% of the cases the technician decided not to repair. In 68% (15/22) of those cases (or 15% of all cases) it was identified as 'technically unfeasible'. Most recurring failure categories identified in literature are described in more detail below.

- *Failure modes related to water circulation (19%)*
  A number of consumer surveys carried out in different countries confirmed that water leakage is one of the key failure modes (38,39). Water leakage can be caused by a number of different failure modes. An often reoccurring issue is the drain pump that is blocked or damaged (34,39). Based on insurance claims related to water damage caused by washing machines, the supply hose is identified as a critical component and, on top of regular inspection, replacement is recommended every 5 years (41). According to manufacturers, water leakage can also occur from poor installation (40). Other identified issues are failures of the valves (that require replacement in 93% of the repaired failures) and filters (that can be repaired without replacement in 73% of the repaired failures) (34).

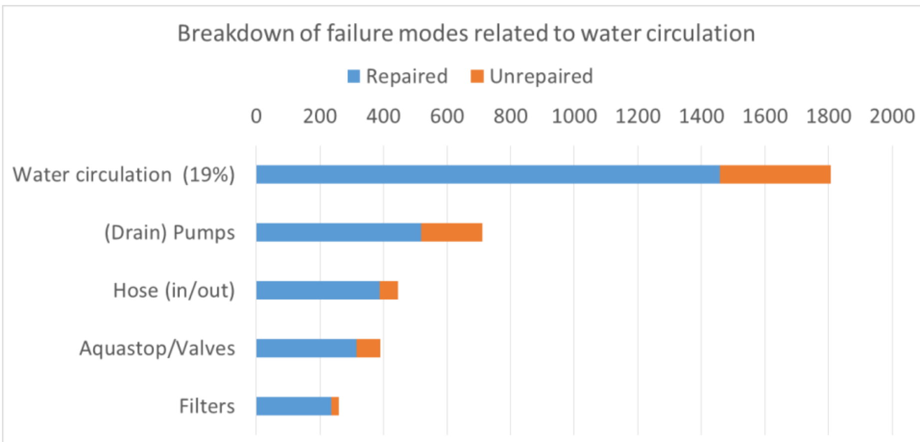


Figure 16: Identified failure modes related to water circulation – modified from (34)

- *Failure related to motor (18%)*
  A component of the motor that often requires replacement is the carbon brush, unless the washing machine is equipped with a brushless motor (40). Failure modes related to carbon brushes are often successfully repaired (78%) and almost always require a replacement part (98% of the repaired failures) (34). Another component related to the motor that often requires replacement is the drive belt (34).

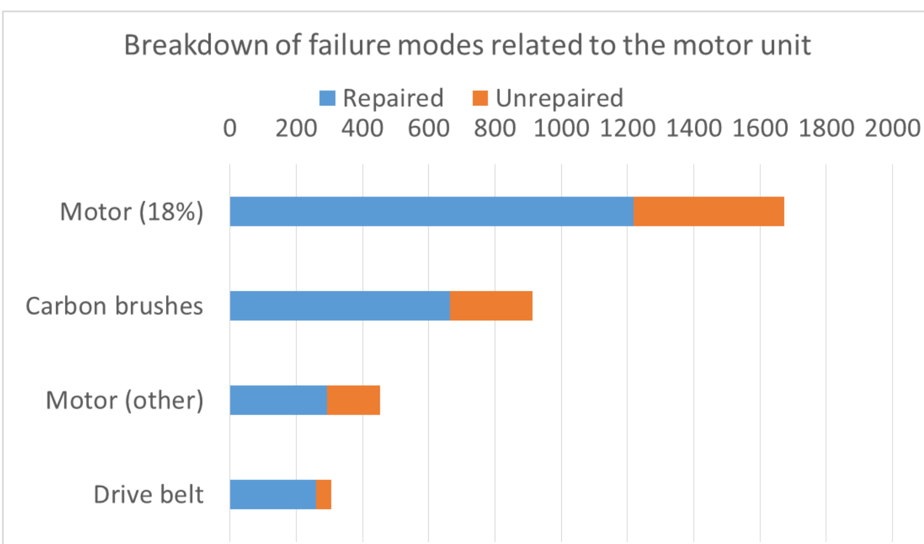


Figure 17: Identified failure modes related to the motor unit – modified from (34)

- <u>*Failure related to the washing unit (16%)*</u>
  Failure related to shock absorbers have a repair success rate of almost 60% and often require replacement (98% of the repaired failures) (34). Repairing the drum, tub and bearings has been recognized by repair service providers and consumers as being difficult (34,38–40). This can partly be explained by the occurrence of combined failures resulting that multiple components requiring replacement (34). In some cases, the bearings can get pressed into the plastic outer casing of the washing machine drum which stops the drum from rotating and can also deform or even break the drum spider (39). As multiple components need to be replaced, failures related to the washing unit mostly remain unrepaired due to high cost of washing unit spare parts, which vary between 60-100 % of the washing machine's original price (34).

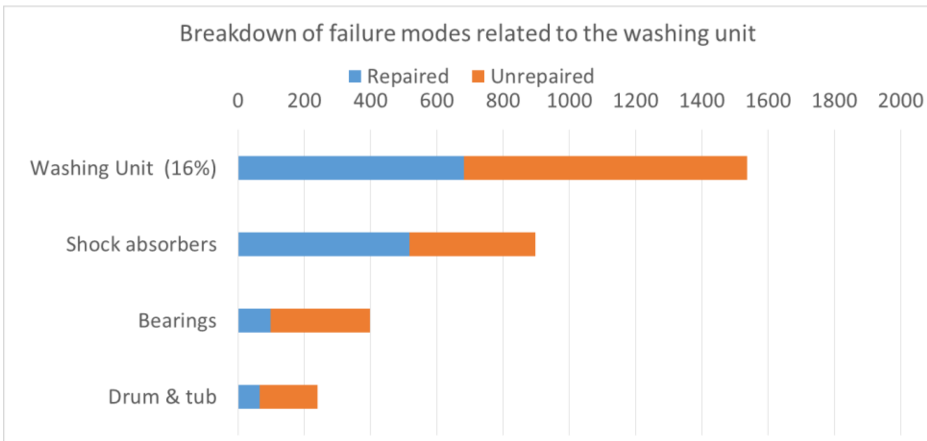


Figure 18: Identified failure modes related to the washing unit – modified from (34)

- <u>*Failure modes related to electronics (14%)*</u>
  Although most of the electronics are located towards the top of the machines to prevent water damage, manufactures have reported electrical failure in the PCBs as a leading fault (40). Consumer based researched also confirmed electronic control systems as a key failure for washing machines (38,39). Observed electronic failures are mostly related to the hardware level. However, it is expected that there will be an increase in software failures due to the increasing number of functions implemented (34).

  Electronics in washing machines are generally difficult to repair with an overall success rate for this aggregated category of 49% (34). Diagnosing failures in the electronic boards is sometimes problematic, especially when boards are sealed and can only be accessed and replaced with high difficulties (42).

  Access to special diagnosis software for repair operators is a key element for the correct diagnosis of the failure mode (39). It has been reported that 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 product or (3) it was impossible to delete the failure code (34). The software, training and 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 (39,42).

- *Failure modes related to doors (11 %)*
  Overall, failures related to doors are found to be relatively easy to repair (34,39,40,42). However, technicians note an increasing need to replace the whole door for more recent designs (34). The seal and lock are mostly reported as failed component for doors and typically required replacement (34). Seals become damaged through misuse or mould accumulation (40). Finally, door hinges that are welded to the washing machine are difficult to replace due to low accessibility (39,42).

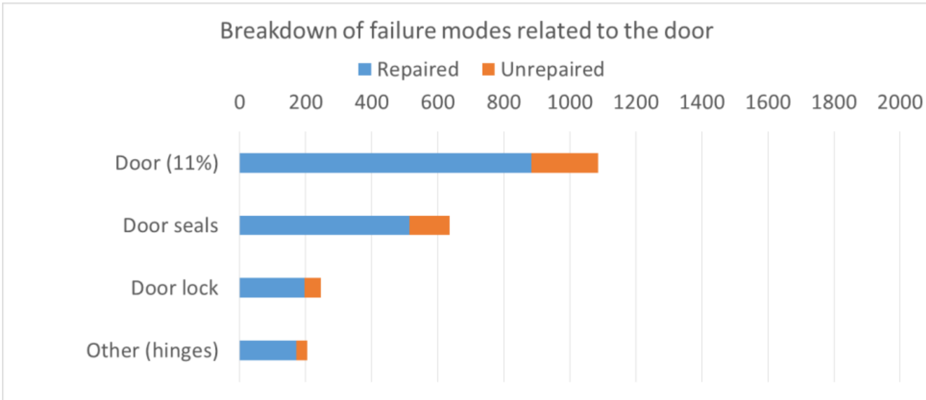


Figure 19: Identified failure modes related to the door – modified from (34)

- ***Estimated repair time and key challenges for most frequent failure modes***
  To gain more insight in the main challenges related to repairing washing machines a survey was carried out with a specialized repair shop for washing machines. A number of experienced repair operators were interviewed and asked to score the relevant and frequency of reoccurring failure modes and conducted repairs. *Table 8* summarizes the results of that survey.

Table 8: Survey of a repair shop for washing machines

Failure	**Time required**	**Key challenge**
Carbon Brushes	30-60 min	Accessibility of failed part
Electronics	<30 min	Diagnosis of the failure
Shock absorbers	<30 min	Accessibility of failed part
Heaters/thermostats	<30 min	Accessibility of failed part
(Drain) Pump	<30 min	Accessibility of failed part
Foreign objects	<30 min	Accessibility of failed part
Doors	<30 min	Diagnosis of the failure
Motor	30-60 min	Spare parts (cost): the motor as a part for older WM and the engine module for more recent models
Hose	<30 min	Accessibility of failed part
Aquastop/valves	<30 min	Diagnosis
Filters	<30 min	Accessibility of failed part
Bearing	60-90 min	As a whole too time consuming; the bearing are mostly glued
Drum/tub	60-90 min	Same as previous: bearing and tub are glued together
Switches	<30 min	Availability of switches
Drive belt	<30 min	Accessibility of failed part

- ***List of key components for the selected product group***

  The failure modes that most often require replacement of parts are the carbon brushes (98% of repaired cases), shock absorbers (98%), aquastop/valves (93%), heater and thermostat (89%) and door and door parts (88%) (34). 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%) (34).

  The following parts are considered to be key components that, when present, should be accessible without damage to the accessed component or other product components in order to be replaced or repaired :

  - Washing unit: shock absorbers;
  - Doors: locks and seals;
  - Motor: carbon brushes and drive belt;
  - Electronics: control boards;
  - Drain pump
  - Heater
  - Inlet valves and aquastop
  - Switches
  - Drain hose and inlet hoses
  - Filters

  For the electronics, the priority is given to control boards related to the program selection and timer. Other electronic, for example related to the engine, are assumed to be more reliable (40). Pressure chamber/air hose (for cleaning) and pressure control were not included as it represents 2% of the identified failure modes (34). Door handles and hinges are regarded as non-key components in this study.

5.2 Description of evaluated model

- ***Information available to consumers***

  The information is provided to consumer through the following documents:

  - User and installation guide: A 44 page document that covers many aspects such as guidance for normal (and environmental friendly) use, safety instructions, installation instructions, general introduction to product interface and the different programs/features, maintenance guidance and troubleshooting. The cleaning and maintenance chapter includes instruction to avoid or remediate detergent build up and blockage of drain pump/outlet hose/filter. The repair advice section includes a detailed list of issues (error codes) and proposed solutions with referral to previous section for detailed instruction.
  - Overview of washing programs: A detailed overview of all possible washing programs including their water and energy use.
  - Exploded view and available spare parts list

- ***Information to (authorized) repair centers***

  Following documents are only made available to authorized repair centers:

- Program Overview: the different washing programs are explained in detail. At the end of the document possible options and their impact on washing programs is also provided.
- Circuit and connection PLC diagrams
- Repair instruction – Test programs**:** overview of error codes explanation and instruction to proceed with general testing (safety and automatic) of specific test of different components (motor, valves, pump, heater, water level, turbidity, flow sensor, display).
- Repair instruction - General: the document contains some repair/troubleshooting information but also many instructions related to dealing with stains on laundry. Only 3 sections provides specific repair advice for professional repair operator.
- Repair instruction – detailed: elaborate fault diagnosis based on some general malfunctions, damaged washing, noise, odours or leaks followed by some basic tests of the heat-sensor (NTC) and Brushless Direct Current (BLDC) motor. Specific detailed instructions are given to replace the combined power and motor unit (PUMU) and the NTC sensor

- ***Failure statistics***

No specific data on specific failure statistic for the case study model was made available to the project team. However, the technical call rate (TCR) is defined as share of products that fail during the warranty period is below 3%. This is a company target for all electronic products put on the market.

For this study the assumed contribution of each part to the overall failure of the washing machine is taken from literature (34).

- ***Ease of disassembly - eDIM***

The eDIM was established for the assessed washing machine. A complete disassembly test was performed including 38 disassembly steps. In total there are 164 connections of which 40 are screws. Overall 24 tool changes were required for the total disassembly of the product. The disassembly amounts to 1140 s and reassembly to 1183 s resulting in a total disassembly eDIM of 38 min.

Table 9: eDIM summary results for selected washing machine for case study 1

	Disassembly							Reassembly							
	Tool Change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	Total Disassembly (s)	Tool change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Fastening (s)	Adding (s)	Total (Re) Assembly (s)	Total (s)
WM	30	187	113	256	517	36	1140	32	187	113	241	573	36	1183	2318

Although total disassembly provides information about the design of the product, in case of repair often only partial disassembly and reassembly is required. Therefore, the eDIM of the identified key components was calculated and the results are given in *Table 10*.

The results confirm that most parts related to the washing unit have a low accessibility. Based on the eDIM values, the shock absorbers, the outlet hose, circulation pump and heater are relatively time consuming to replace or repair as the partial eDIMs represent about 20% of the eDIM for total disassembly. The remaining identified key components are considered to be relatively easy to access as the eDIM is around 10% or less of the eDIM for total disassembly.

Table 10: eDIM of partial disassembly for relevant parts of WM

Disassembly target	Number of steps	Number of tool changes	Number of connections	eDIM (s)	% of total disassembly and reassembly
Total disassembly	38	24	164	2318	
(Drain) Pumps	7	4	15	432	19%
Hose (in/out)	9	7	27	487	21%
Aquastop/Valves	3	0	5	196	8%
Filters	1	0	4	42	2%
Motor (other)	4	3	11	259	11%
Drive belt	3	3	8	232	10%
Shock absorbers	6	8	26	468	20%
Bearings	15	13	69	1103	48%
Drum & tub	15	13	69	1103	48%
Electronics (programs)	5	2	8	253	11%
Door seals	6	1	9	209	9%
Door lock	5	3	10	248	11%
Other (hinges)	4	3	8	224	10%
Heater & thermostats	6	6	31	395	17%

- ***Spare parts***

Spare parts for the washing machine are available and easily identified by the customer on the manufacturer's website through an interactive exploded diagram for each product reference. The company aims to have all spare parts available for a minimum period of 10 years. A number of relevant spare parts are listed in *Table 11*.

In this specific model, the motor is a BLDC motor and therefore there is no need to replace the coal brushes.

The bearing cannot be replaced separately and if required the back of the tub, in which the bearing is pressed, will be replaced as a whole. Based on the manufacturer own experience, the failure rate of the bearing is considered to be rather low. A recent study also confirms that bearing failures represent less than 5% of the overall identified failure modes of 6672 serviced washing machines and that this type of failure is rarely successfully repaired (only 25% of failures were repaired) (34). This is not only due to the high spare part cost (in this case 18% of catalogue price) but also due to the labor intensive nature of replacing parts of the washing unit.

The cost of the operating and power module covers almost 18% and 25% of the catalogue price respectively. The cost of such PCB components has been reported as a barrier for repair by the in this study interviewed repair centers.

Other expensive spare parts are the tub and motor. All other spare parts are made available by the manufacturer at <10% of the catalogue price.

Table 11: Overview of relevant spare parts consumer price for selected WM

Spare part description	**% of catalogue price**
(Drain) Pumps	4%
Hose (in/out)	1%
Aquastop/Valves	8%
Filters	2%
Motor (other)	14%
Drive belt	4%
Shock absorbers	8%
Bearings	18%
Drum & tub	37%
Electronics (programs)	18%
Electronics (motor)	25%
Door seals	8%
Door lock	3%
Other (hinges)	1%
Switch	2%
Display panel	8%
Heater & thermostats	9%

- ***Service***

Specific contact details for repair support are available on the manufacturer's website. A dedicated call center can be reached 24/7 and will provide support for all stages of the repair. However only a number of failures are expected to be repaired by laymen. For other failures an authorized repair professional should be involved.

Through the website there is the possibility to book a repair technician visit. The cost of the offered repair service are explained in detail.

Based on product model reference number, all relevant documents (user manuals, troubleshooting, spare parts) can be retrieved on the website. In order to facilitate the access to relevant documentation and information, the customer can register all their products on the website and link them to a personal account.

The manufacturer also provides additional warranties for products (3 additional years). For washing machines the additional warranty can be purchased for approximately 90 Euro. Furthermore, on a number of specific components, an extended warranty of 10 years is provided if the product is registered after purchase. This warranty on specific parts only covers the cost of the spare part and does not include labor or travel costs related to the required repair.

5.3 Repairability assessment

- ***Product Identification***

Ease of identification

Brand, model series, and GTIN EAN code with corresponding barcode and E-number have been included in three labels. The product reference codes are readable and have an approximate point size value of 11+.

Option selected: *Brand and unique model version reference at least point 10* and GTIN code integrated in black/white barcode or QR code*
Score: *10/10*

Accessibility of identification

These labels are accessible without the need of any tools: (1) inside the closing ring (2) at the right side and (3) at the back of the washing machine. In addition, the brand and model series name are printed on the housing.

Option selected: Accessible after manual operation without disconnecting components
Score: 10/10

Robustness of identification

All three labels have been glued on the product. Additionally, the brand name and model type and functions have been printed directly on the product housing. However this information printed on the housing does not allow to identify a specific unique product reference.

Option selected: *All or part of the product identification information is included on removable labels e.g. glued*
Score: *2/5*

Availability of identification support

There is no limit to the number of years after purchase that service would be available. Because for some specific components a warranty of 10 years is provided, the minimum service is also assumed to be 10 years.

Option selected: *Technical support from manufacturer available for product identification for at least 10* years after last production*
Score: *5/5*

Accessibility of identification support

The website of the manufacturer allows customers to register their washing machine online with the E-number and the FD-number by creating a dedicated account. If necessary, additional information is given to find the labels on the product. In addition, general contact information including e-mail, and phone numbers are provided. For general question related to products or services, a call center is available on weekdays from 8.00 through 17.30. For specific questions related to repair, a technical expert is available 24/7 and a repair appointment can also be booked online for specific product categories including washing machines.

Option selected: Toll-free or web-based support available for product identification.
Score: 5/5

- ***Failure Diagnostic***

Instructions for problem identification - content

As described in previous *section*, different information is available to customers and professional repairers.
All customers have access to basic troubleshooting, maintenance instructions and caution warnings. The troubleshooting information is limited to the failures that are considered to be repairable by a layman with no specific technical skills in a safe manner. A hard copy of this information is provided with the product and it can be found online.
In addition to this information, professional repairers have access to detailed failure diagnostics and repair instructions for all possible failure modes and error codes. To obtain this information the professional repairer must be registered and has to follow training offered by the manufacturer.

For professional repairers:
Option selected: Repair instruction includes the following elements:
- safety measures
- fault diagnostic advice: (check)list of identified root causes for common failures and troubleshooting tree*
- test method to check working condition of priority part
- complete list of error codes and required repair actions, if applicable
- diagrams of the Printed Circuit Board, if applicable
- fault detection software , if applicable
Score: 10/10

For consumers:
Option selected: Repair instruction includes the following elements:
- safety measures
*- basic fault diagnostic advice: (check)list of identified root causes for common failures**
*- test method to check working condition of key functional parts**
- limited list of error codes and required repair actions, if applicable.
Score: 5/10

Product designed for easy failure detection

Faults and errors are displayed through a coded interface. These codes are documented and tailored to targeted user, i.e. customer and professional repair technicians.

Option selected: Coded interface - Cause of failure can be established by means of the control panel/display. Supporting documentation (e.g. error codes) could be required.
Score: 5/10

Availability of failure diagnostic support

Reportedly, all owners of products from the manufacturer will receive support from the manufacturer customer service desk. However, the level of support may not be the same during (extended) warranty and outside warranty period.

Option selected: Technical support from manufacturer available for failure diagnostic for at least 10 years after last production.*
Score: 5/5

Accessibility of failure diagnostic support

Failure diagnostic support is available online and can be searched based on e-number of products. Additionally customers can contact the help desk for support to identify issues with products and evaluate the need for appointment with a technicians

Option selected: Toll-free or web-based contact available for failure diagnostic allowing customer to identify issues and required repair actions.
Score: 5/5

- ***Disassembly and Reassembly***

Disassembly instructions – content

The installation and maintenance procedure is publicly available for free. Although this guide includes relevant information on accessibility of parts that are recommended to be cleaned, it does not provide specific disassembly information for repair. It also does not include a list of required tools or connectors. An exploded diagram for each product model is available online.

More detailed disassembly and reassembly documentation is only made available after registration as professional repairer. No standardized format is used for the disassembly and reassembly information.

For professional repairers:
Option selected: Disassembly instructions include the following elements:
- exploded diagram (include minimum size)*
- list of connectors used & required tools
- description of recommended disassembly steps to remove priority parts
Score: 10/10

For consumers:
Option selected: Disassembly instructions include the following elements:
- exploded diagram
Score: 2/10

Product designed for ease of disassembly

The average eDIM for partial disassembly is almost 7 min which represents 18,4% of the eDIM for total disassembly. When the failure rates described in chapter 2 for WM are taken into account, a weighted average for partial disassembly of 6,4 min is calculated.

Option selected: Average ease of disassembly: average eDIM for partial disassembly represents between [15%-30%] of eDIM for total disassembly
Score: 5/10

Required tools for disassembly

Priority parts can be removed with the common general purpose tools (*Table 5* list A) and some specific hex bolt sizes from specialized commercially available tools (*Table 6* list B). More specialized tools are required for specific repair actions such as testing the NTC sensor. However, this is not considered to be a priority part.

Option selected: Priority part(s) can be replaced using specialized commercially available tools (from specific list B see Table 6)*
Score: 2/10

Availability of technical support for disassembly and reassembly

Reportedly, all owners of products will receive support from the customer service desk. However, the level of support may not be the same during (extended) warranty and outside warranty period.

Option selected: Technical support from manufacturer available for disassembly and reassembly for at least 10 years after last production.*
Score: 5/5

Accessibility of technical support for disassembly and reassembly

Technical support is provided through local call centers for which local contact information is available. As standard phone numbers are used, local calling rates are assumed.

Option selected: Local fee contact available for disassembly and reassembly.
Score: 2/5

- ***Spare Parts***

Information for spare parts

Based on the E-number (model number) all parts are listed on the manufacturers website with an exploded view including parts reference and price. The spare parts can be purchased from the manufacturer.

Option selected: Information related to spare parts include the following elements:
- Information on spare parts supply (address , web shop)
- Spare part register including unique reference numbers of available spare parts
Score: 10/10

Information for 3D printing of spare parts

No information regarding 3D printing of components is provided.

Option selected: Not available
Score: 0/2

Modular design of the product

The list of key components proposed in Chapter 2 is used for assessing the modularity of the washing machine. The following components is defined as separate spare part:

- Shock absorbers including a connection kit
- Door hook, seal, hinges and window
- Drive belt
- Programmed or unprogrammed operating modules
- Drain pump
- Heater
- Inlet valves and aquastop
- Switches

No carbon brushes are present in assessed washing machine model.

Option selected: All priority parts can be replaced individually*
Score: 10/10

Standardized design

The generic spare parts can be used in several models, however not all priority parts are standardized. For example the connection kit for the shock absorbers is very specific to manufacturer of the washing machines.

Option selected: A number of priority parts are standardized*
Score: 2/5

Supply of spare parts – content

As discussed above, all priority parts are available as spare part.

Option selected: Compatible spare parts for priority parts are widely available for this product 100% * (by count)*
Score: 5/5

Supply of spare parts – availability

Based on information received from the manufacturer, spare parts are available for at least 10 years after final production date.

Option selected: Long-term availability of spare parts for at least 10 years after last production*
Score: 5/5

Supply of spare parts – cost

The average consumer price of all priority parts is 7,3% of the catalogue price of the washing machine. If the failure rate of each priority part, as described in Chapter 2, is taken into account a weighted average of 7,93% is calculated.

Option selected: Average consumer price of available parts is between 5 and 10% of catalogue price (10% included)*
Score: 5/10

- ***Prepare for Reuse***

<u>Instructions for reconditioning of product</u>

No dedicated factory settings are implemented in the design. In the repair manual, a short description of recommended measures after repair is described. Additionally, the service technician is instructed to follow the DIN standard VDE 0701 for preparing electrical products for reuse after repair, or other country-specific regulations.

<u>Option selected:</u> Repair instruction includes procedure to reset to default / factory settings and restore product to working condition, as appropriate.
<u>Score:</u> 5/5

<u>Product designed for ease of restoring to working condition after repair</u>

Most of the error codes can be removed without the need of an external specialized device. In general, after errors have been solved it is recommended to shut down and restart the washing machine. In cases of software issues, re-flashing the hardware of the washing machine with a dedicated device by trained repair technicians is required.

<u>Option selected:</u> Product resetting can be done without intervention with an external / specialized device.
<u>Score:</u> 2/2

<u>Technical support for reconditioning – accessibility</u>

Technical support is provided through local call centers for which local contact information is available. As standard phone numbers are used, local calling rates are assumed.

<u>Option selected:</u> Local fee contact available for reconditioning.
<u>Score:</u> 2/5

5.4 Repairability assessment results

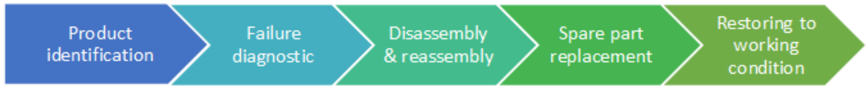
The repairability was assessed both from the perspective of the consumer and the professional repairer. In the case of the washing machines, 'professional repairers' are those repair organisations that have successfully followed a specific training and are registered with the manufacturer. Repair is thus facilitated by the manufacturer with those repair organisations that have shown a minimum of expertise in order to ensure a certain level of quality offered to the consumers when looking for professional repair support.

If a different score applies to consumer for a specific criterion, this is explicitly mentioned in the repair assessment described in previous section. The consumer score would also be applicable to a professional repairer that has not registered with the manufacturer.

Overview of criteria scores:

	Nr	Criterion description	Score Consumer	Score Repairer	Max
Repair Step 1: Product identification	1.1	Ease of identification	10		10
	1.2	Accessibility of identification	10		10
	1.3	Robustness of identification	2		5
	1.4	Availability of identification support	5		5
	1.5	Accessibility of identification support	5		5
Repair Step 2: Failure diagnostic	2.1	Instructions for problem identification - content	5	10	10
	2.2	Product designed for easy failure detection	5		10
	2.3	Availability of failure diagnostic support	5		5
	2.4	Accessibility of failure diagnostic support	5		5
Repair Step 3: Disassembly and reassembly	3.1	Disassembly instructions - content	2	10	10
	3.2	Product designed for ease of disassembly	5		10
	3.3	Required tools for disassembly	2		10
	3.4	Availability of technical support for disassembly and reassembly	5		5
	3.5	Accessibility of technical support for disassembly and reassembly	2		5
Repair Step 4: Spare part	4.1	Information for spare parts	10		10
	4.2	Information for 3D printing of spare parts	0		2
	4.3	Modular design of the product	10		10
	4.4	Standardized design	2		5
	4.5	Supply of spare parts - content	5		5
	4.6	Supply of spare parts - availability	5		5
	4.7	Supply of spare parts - cost	5		10
Repair Step 5: Resetting to working condition	5.1	Instructions for reconditioning of product	5		5
	5.2	Product designed for ease of restoring to working condition after repair	2		2
	5.3	Technical support for reconditioning - accessibility	2		5

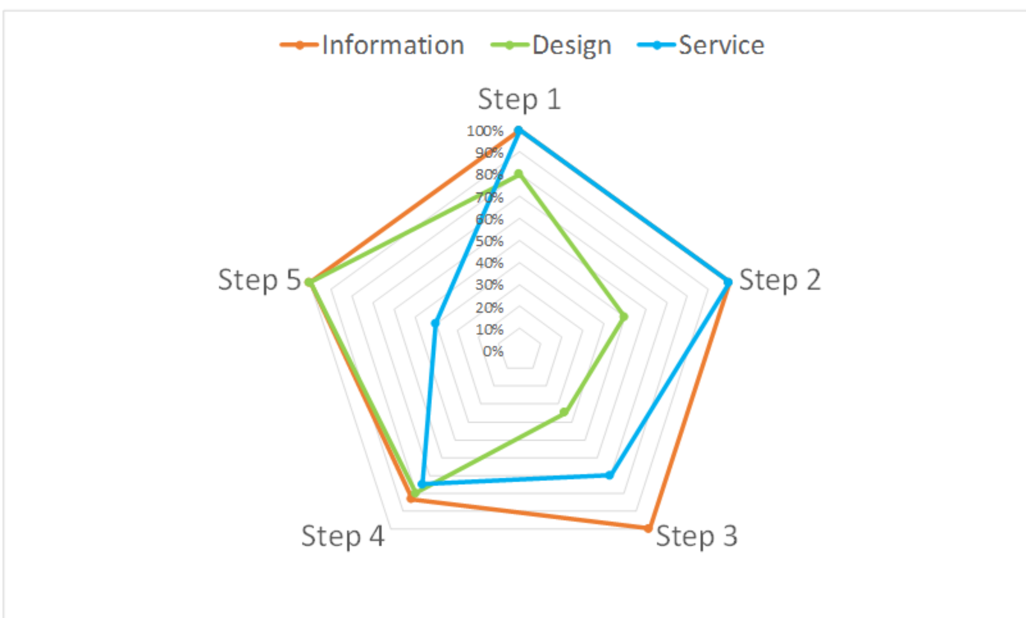
Summary: Final Repairability Score – Professional Repairer



Maximum scores	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	10	10	10	12	5	47
Design	15	10	20	15	2	62
Service	10	10	10	20	5	55
	35	30	40	47	12	164

Achieved assesed product scores	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	10	10	10	10	5	45
Design	12	5	7	12	2	38
Service	10	10	7	15	2	44
	32	25	24	37	9	127

Repairability score	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	100%	100%	100%	83%	100%	96%
Design	80%	50%	35%	80%	100%	61%
Service	100%	100%	70%	75%	40%	80%
	91%	83%	60%	79%	75%	**77%**



Chapter 6: Case Study 2 Vacuum Cleaners

6.1 Definition and characterization of selected product groups

- ***Definition and functionality***

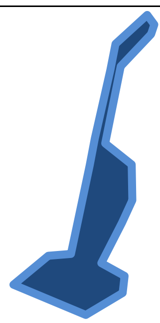
Generally, a vacuum cleaner can be defined as: “An electrically operated appliance that removes soil from a surface to be cleaned by means of an airflow created by under pressure developed within the unit. The material thus removed is separated and stored in the appliance and the cleaned suction air is returned to the ambient” (43).

The eco-design regulation for vacuum cleaners applies to electric mains-operated vacuum cleaners, including hybrid vacuum cleaners. ‘Hybrid vacuum cleaner’ means a vacuum cleaner that can be powered by both electric mains and batteries. The regulation excludes wet, wet and dry, battery operated, robot, industrial, or central vacuum cleaners as well floor polishers and outdoor vacuums.

- ***Technology: different designs and engineering solutions***

Vacuum cleaners (VC) are made in a variety of shapes and sizes for domestic use. The main product types are listed in *Table 12*.

Table 12: Vacuum cleaner product types (44)

	**Upright Cleaners** The cleaning head forms an integral part of the cleaner housing. The complete cleaner is moved over the surface to be cleaned by means of an integral handle. It is suited to cleaning carpet and floor areas. ***Stick vacuum cleaner*** is similar to an upright vacuum but with a compact, lightweight design for increased manoeuvrability.
	**Cylinder or canister vacuum cleaners** The cleaning head is separated from the vacuum body usually by means of a flexible hose. The body contains the motor, separation system, filtration system, and exhaust. This type of cleaner is supplied with a fixed or at least one detachable nozzle designed for cleaning both carpets and hard floors.
	Handheld vacuum cleaners are compact and convenient. They are usually cordless and rechargeable.
	Robot vacuum cleaner means a battery operated vacuum cleaner that is capable of operating without human intervention within a defined perimeter, consisting of a mobile part and a docking station and/or other accessories to assist its operation

Before Dyson introduced the bagless vacuum cleaner in the early ‘90ties, bagged vacuum cleaners were the only product type on the market. In the conventional bagged vacuum cleaners, a vacuum bag is used to filter dirt out of a stream of air while a removable container and a reusable filter is used to trap dirt in a bagless vacuum cleaner. Both product type have a similar performance in terms of cleaning ability and energy consumption (44). Bagless vacuum cleaners tend to predominate in the UK but bagged machines still command a large part of the market in other EU countries, such as Germany (45). VCs are produced as electric mains-operated product as well as battery operated or cordless products. Handheld vacuum cleaners are usually cordless.

In order to prevent dust and dirt from re-entering the atmosphere vacuum cleaners require filtration. Typical filter types are the HEPA (High Efficiency Particulate Air) and cyclonic filter. Cyclonic filtration system are usually used in a “bagless” VC (44).

- ***Capacity and performance***

There are two major standards applicable to vacuum cleaners in Europe and these are EN 60335.2.2 and EN 60312. EN 60 335 is relevant to safety and describes the method by which input power is defined. Nominal input power is the arithmetic average of maximum input power (watts) and minimum input power (watts). EN 60312 is relevant to performance and contains many test methods to measure performance relative to cleaning on different surfaces and with different types of soiling.

In 1980, the average input power ratings of vacuum cleaners were around 350 watts for uprights and between 600 and 1100 watts for canister vacuum cleaners. By 2008, this had increased to between 1000 and 2000 watts for uprights and 1200-2700 watts for canister cleaners. Due to the implementation of the eco-design requirements for vacuum cleaners, the rated input power was limited to 1600 W in September 2014 and to 900 W in September 2017. There is no correlation between the rated input power and the cleaning capacity (44).

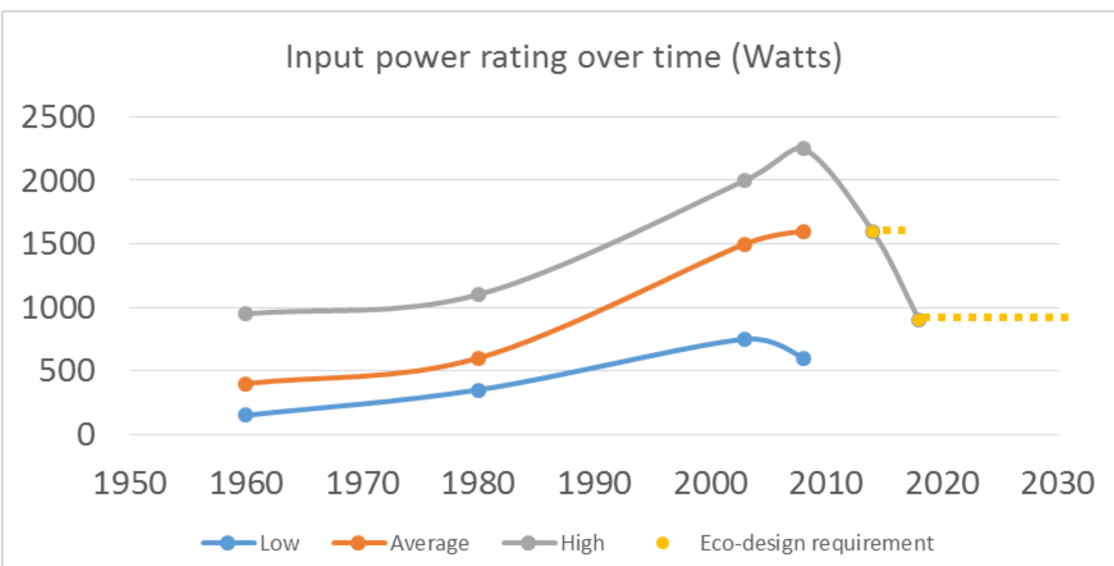


Figure 20: Input power rating over time for VC in the scope of the eco-design regulations (45)

The eco-design regulations also limited the annual energy consumption to 62 kWh in 2014 and 43 kWh in 2017. The annual energy consumption is based on a usage of 1h per week.

- ***Average product/components lifetime***

The expected lifetime of VCs ranges between 5 and 9 years (45,46). A representative figure of 8 years can be assumed and corresponds to the median of the Weibull distribution for vacuum cleaners described in (36). From the given Weibull distribution in (36), a constant failure rate (average) of 9,7% can be deduced for 2005.

A survey of members of the UK consumer organization about product reliability showed that at least 1 in 5 upright vacuum cleaners in the survey required repair during the first 6 years, compared with around 1 in 10 for canister models (45). A similar survey in 2016 revealed that the number of canister vacuum cleaners with failure increased to 15% (47)

The motor is regarded as a critical component as the motor failure usually corresponds with the disposal of the vacuum cleaner (45). Therefore, durability requirements have been enforced for a minimum operational motor lifetime of 500 h (43). A Dutch consumer organisation has tested the motor of a number of different vacuum cleaners (48). The lifetime of the motors was analysed for in total 51 vacuum cleaners of 10 different brands and the results are shown in *Figure 21*. In all cases the coal brushes of the broken motor were worn out. The results also indicated a relationship between the length of coal brushes and the product lifetime of the motor. One product (Samsung 1) did not contain any carbon brush.

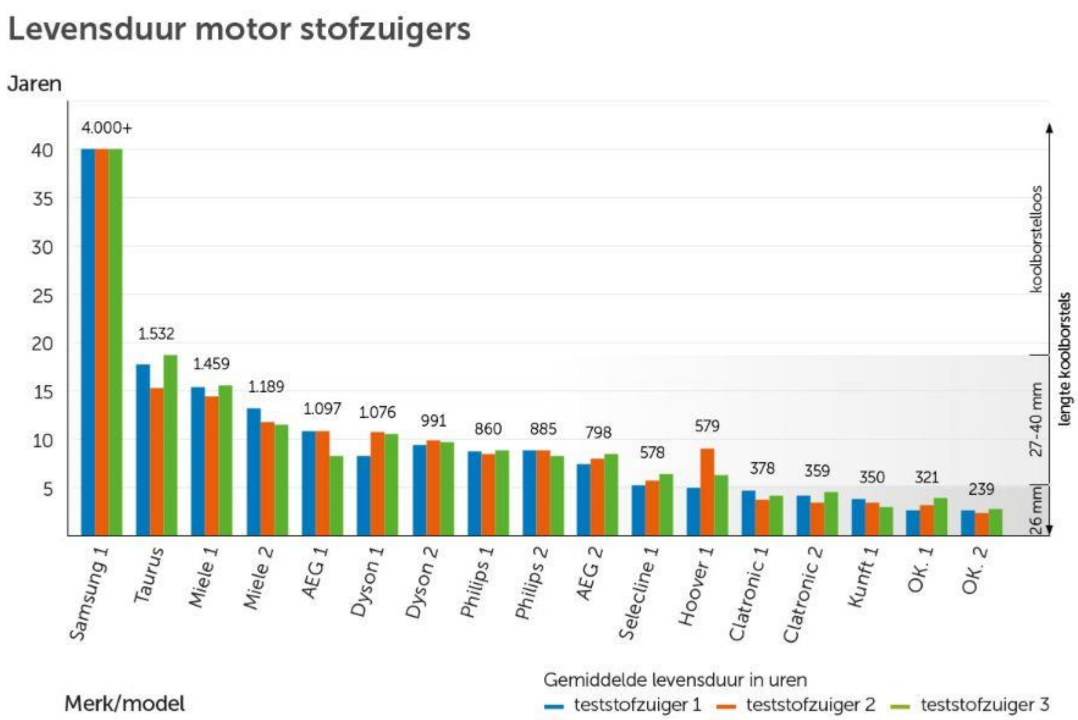


Figure 21: Lifetime test on VC motors performed by Dutch consumer organisation Consumentenbond (48)

The German consumer association Stiftung Warentest has also performed durability tests on the motor of 190 VCs over the period 2003-2015. These data show that 170 of 190 vacuum cleaners (89%)

reached the limit of 600 hours. This percentage seems to be fairly constant in time and mostly independent of the price (49).

In addition to durability requirements for the motor, the eco-design regulation for Vacuum Cleaners also includes durability requirements for the hose ("the hose, if any, shall be durable so that it is still useable after 40,000 oscillations under strain") (43).

- ***Overview of possible failures and upgrades of the selected product group***

The main failures reported by users to different national consumers organizations are listed in *Table 13*. The Belgian consumer organization "Test Aankoop" has carried out a survey with 19000 users (50). They have listed the top five reported failure mode which represents 40% of all reported failure modes. The Dutch organization "Consumentenbond" also listed some key failure modes but did not report any additional statistics (48). The UK consumer organization "Which?" carried out a survey in 2015 including 350 respondents for upright VCs and 287 for canister VCs. The results of the survey also include problems that consumers experience do not always coincide with a failure. For example both 'brush not working properly' and 'brush not working at all' or 'handle loose' and 'handle broken' have been included in the results.

Table 13: Failure modes occurrence rate for VCs based on consumer surveys (48–50)

	Consumentenbond (2017)	Test aankoop (2015)	Which? (2015) - Canister	Which? (2015) - Upright
Split/broken hose	X	15%	5,27%	7,71%
Power cable	X	11%	9,73%	4,95%
Brushes/Nozzel	X	5%	12,19%	21,55%
Switches/Electronic board	X	5%	1,64%	
Wheels	X	4%	1,64%	2,76%
Motor (carbon brushes)	X		4,52%	7,54%
Broken casing			6,92%	5,01%
Filters	X		12,19%	12,21%
Foreign obstruction	X			
Handle			3,77%	3,88%
Suction deteriorated			16,92%	19,30%
Broken accessories			8,36%	4,67%
Overheating			5,96%	3,55%
Other			10,75%	4,84%

- ***List of key components for the selected product group***

Although there is less data available to prioritize parts, the following parts are considered to be key components that, when present, should be accessible without damage to the accessed component or other product components in order to be replaced or repaired:

- Hose / tube
- Motor (carbon brushes)
- Brushes/Nozzles (belt for rotating brush)

- Power cable
- Electronic boards (increasing complexity of VCs)
- Wheels

As mentioned previously, motors of VCs typically rely on carbon brushes to supply electrical power to the rotating armature. These carbon brushes tend to wear down and because in most cases a domestic vacuum cleaner motor cannot be serviced. As a result, at the end of the carbon brush life the motor (or product) is currently replaced (45,46). An alternative, to avoid this issue, is using a new generation of electric motors without carbon brushes (45).

As VCs become more sophisticated more electronic components are included in the design. Electronic boards are not only used to control motor speeds and power but also to send feedback from the suction head to modify suction power dependent upon dirt entering the machine or the "clogging" of bags or filters(45). Therefore it is expected that electronic boards will become more important as key components of VCs.

Finally, although filters are often reported by consumers as a failure, the replacement of a filter is considered to be proper maintenance of the VC. Therefore filters are not considered to be key components for repair but rather consumables for usage of the VC.

6.2 Case 2a: Canister vacuum cleaner

- ***Information for consumers***

Several documents are supplied with the product and can also easily be retrieved online, especially if the customer has registered his or her product.

The following documents are available:

- Brochure: a document that gives a brief description of the product and summarizes the key features, at the end a number of specifications are also included.

- User Manual: The documents included an simplified exploded view of the main large parts that need to be assembled before using the product. Some instructions are also provided for emptying the dust container and regular monthly maintenance/cleaning. All instruction are given with pictograms .

- Important Information Manual: Some user advice and safety provisions (danger, warning and caution) are given in this manual. A link is given to manufacturer's online web shop for ordering parts/accessories, towards a general document related to warranty and online support hub. Finally, a table of common troubleshooting is given (problem description, possible cause and proposed solution)

- ***Information for professional repairer***

A service manual is made available to authorized repair centers, which service is within the warranty period. Although the information related to disassembly and reassembly is not provided in a standard format, it is very useful information before engaging in disassembly activities of the device. The service document also includes an exploded view with indication of connectors. Although the type of connector (screws) is indicated, the required tools are not mentioned (specific type and size of tool).

The service document includes a parts list that can be order for replacement. There is a total of 34 parts defined of which a number include subparts. The service manual document also includes a circuit diagram.

The service document does not include any other specific 'repair instruction' (section is left blank).

- ***Failure statistics***

Although the manufacturer did provide additional insights into failure of specific components, the details of the provided information cannot be reported due to confidentiality aspect. However, the general nature of the provided information is described in this section.

On a regular basis, the manufacturer collects a random sample of products from their contracted repair providers and establishes the failure mode for each item. From these tests, the manufacturer has observed that in general a significant part of the returned products show 'No Failure'. In those cases the product is functioning in line with the specification (suction power, noise level, input/output power, design & appearance, all parts included).

Additionally the manufacturer also provided the actual consumption of spare parts for the registered repair of these products since it has been put on the market.

Return rates for the specific models were not available for this study but a typical return rate within warranty period is assumed to be 2-3% for brands with an above average performance in product reliability.

- ***eDIM – ease of disassembly***

The eDIM was established for the assessed canister VC. A complete disassembly test was performed including 34 disassembly steps. *Table 14* summarizes the eDIM results. In total there are 50 connections of which 17 are screws. Overall 9 tool changes were required for the total disassembly of the product. Furthermore, 23 connections are snap fits that required force >20N and 7 connections are classified as loose fit with limited force required (<5N). To remove the bucket assembly a button was included in the design. The disassembly accounts for 411 sec and reassembly 436 sec resulting in a total of 14,1 min.

Table 14: eDIM summary results for selected canister VC

	Disassembly							Reassembly							
	Tool Change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	Total Disassembly (s)	Tool change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Fastening (s)	Adding (s)	Total (Re) Assembly (s)	Total (s)
Canister VC	13	0	2	96	254	46	411	10	0	2	96	283	46	436	847

A "normal" Torx T15 screwdriver with extension cannot be used since it does not fit in the small openings. Therefore a T15 screwdriver with a 14,5 cm shank is required. This specific type of screwdriver is commercially available, but is not a common purpose tool. It can be ordered online on specialized websites, but was not identified in most DIY-shops.

In case of spare part repair or replacement, often only partial disassembly and reassembly is required. Therefore, the eDIM of the identified key components was calculated and the results are given in *Table 15*. Based on the partial disassembly eDIM results, the motor and rear wheels are considered to be less accessible components. Apart from the power cable, all other investigated components are relatively easy to access compared to the total disassembly time.

Table 15: eDIM of partial disassembly for relevant parts of canister VC

Disassembly target	**Number of steps**	**Number of tool changes**	**Number of connections**	**eDIM**	**% of total disassembly and reassembly**
Total disassembly	33	9	50	847	100%
Split/broken hose (incl RC)	2	0	2	20	2%
Tube	3	0	3	30	4%
Motor	19	9	40	756	89%
Brushes/Nozzle	1	0	1	10	1%
Power cable	18	5	25	372	44%
Broken casing	4	1	19	233	28%
Filter casing	6	0	6	43	5%
Wheels	21	7	34	600	71%

- ***Spare parts***

For each product model, customers can easily find accessories or consumer replaceable parts on the manufacturer's website based on model number. Consumer replaceable parts for VC are typically nozzles, tubes, filters, bags. Sometimes the part is supplied by the manufacturer directly but in some cases (e.g. for filters) the customer is referred to other retailers. For the assessed canister VC, a total of 3 items (filter, tube and accessory holder) were identified as consumer replaceable at the time the research was done.

Although the hose was not available for customers on the manufacturer's web shop at the time the research was done, it is available through third party spare part providers. Also the nozzle was not identified as consumer replaceable part on the manufacturer's website at the time the research was done but a similar (and most likely compatible part) can be purchased through third party.

The manufacturer has also identified 34 spare parts that are made available to professional repairers via professional spare parts distributors. Specific prices apply for professional repairer. Although the business to business prices were provided during the course of the study, this information is confidential and cannot be shared in this report.

Therefore, the table below summarize the availability of spare parts for the assessed canister VC model for consumers.

Table 16: Overview of available parts to consumer for the assessed canister VC

Part Description	**Sold by manufacturer % of catalogue price**	**Sold by third party % of catalogue price**
Filter casing		6,2%
Exhaust foam		1,3%
Non-washable filter	5,7%	
Caster assembly		2,6%
Motor		20,6%*
Electronic (Control board)		12,4%*
Hose (including remote control)		16,1%
Tube	6,2%	
Accessory holder	2,5%	
Tri-Active nozzle		16%*

*** similar or potentially compatible spare part**

- ***Service***

There are different channels to reach the customer service of the manufacturer, through a local call centre, chat and email. Local contact details dedicated to specific product groups are provided on the website of the manufacturer. Local calling rates apply and the call centre is also available on Saturday. Even though customers can call the manufacturer after sales care service after the warranty period most contacts are realized during the warranty period.

Through the website there is also the possibility to book a repair service. Further arrangements are done by email with the contracted third party repair centre.

Based on product model reference number, all relevant documents (user manuals, troubleshooting, spare parts) can be retrieved on the website. In order to facilitate the access to relevant documentation and information, the customer can register all their products on the manufacturer's website and link them to a personal account.

The manufacturer offers an additional warranty free of charge (after product registration) of 3 years for VCs, resulting in an extended warranty of 5 years.

6.3 Case 2b: Upright vacuum cleaner

- ***Information for consumers***

Several documents are supplied with the product and also easy to retrieve online, especially if the customer has registered his product.

Following documents are available:

- Brochure: a document that gives a brief description of the product and summarizes the key features, at the end a number of specifications are also included. The manufacturer has also self-labeled the product as environmentally friendly. The specific performance indicators behind the labelling is however not provided

- User Manual: This document applies to a number of similar models. The document includes an exploded view of the main large parts that need to be assembled before using the product. In order to properly charge the VC a wire holder needs to be fixed to the wall (at a height of 53 cm). Some instructions are also provided for charging the battery and different use function (normal power, full power, detachable duster), emptying the dust container and regular monthly maintenance/cleaning. All instructions are given with pictograms

- Important Information Manual: Some user advice and safety provisions (danger, warning and caution) are given in this manual. Relevant links to online information and support are given. A specific section is included on collection of the battery for recycling at end of life. Although it is advised to have a professional remove the rechargeable battery, some instructions are given for this. Finally, also a table of common troubleshooting is given (problem description, possible cause and proposed solution)

- ***Information for (authorized/certified) repair shops***

A service manual is made available to authorized repair centers for the products that they service within the warranty period. The service document does not include any specific 'repair instruction' (section is left blank). The disassembly and reassembly information is similar to the rotating brush cleaning instruction provided to customers (page 11 of user manual). The service document also included a parts list that can be ordered for replacement. There are a total of 16 spare parts defined of which a number include subparts. Not all parts of the VC are considered for replacement. The service manual document also includes a circuit diagram and an exploded view.

- ***eDIM – ease of disassembly***

The eDIM was established for assessed upright VC. A complete disassembly test was performed including 33 disassembly steps. The table below summarizes the eDIM results. In total there are 118 connections of which 60 are screws. Overall 15 tool changes were required for the total disassembly of the product. The disassembly accounts for 803 s and reassembly 912 s resulting in a total of 28,6 min.

Table 17: eDIM summary results for selected upright VC

	Disassembly							Reassembly							
	Tool Change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	Total Disassembly (s)	Tool change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Fastening (s)	Adding (s)	Total (Re) Assembly (s)	Total (s)
Upright VC	20	0	0	231	508	43	803	20	0	0	233	615	43	912	1715

In case of repair or spare part replacement, often only partial disassembly and reassembly is required. Therefore, the eDIM of the identified key components was calculated and the results are given in *Table 18*. Based on the partial disassembly eDIM results, the motor, wheels and battery are considered to be less accessible components. All other investigated components are relatively easy to access compared to the total disassembly time.

Table 18: eDIM of partial disassembly for relevant parts of upright VC

Disassembly target	**Number of steps**	**Number of tool changes**	**Number of connections**	**eDIM**	**% of total disassembly and reassembly**
Total disassembly	33	15	118	1729	100%
Filter casing	3	0	4	29	2%
Broken casing	2	0	3	16	1%
Brushes/Nozzle	1	0	1	6	<1%
Wheels	7	5	17	655	38%
Motor	10	4	47	579	33%
Battery	10	3	44	514	30%

- ***Spare parts***

Table 19: Overview of available spare parts for selected upright VC

Part description	**Consumer Price - sold by manufacturer % of catalogue price**	**Consumer Price - sold by third party % of catalogue price**
Adaptor	7,7%	8,2%*
Filter	3,3%	3,4%*
Cyclone assembly	2,7%	4,5%
Dust separator assembly	1,8%	4,8
Dustbin assembly	2,7%	4,5%
Nozzle - accessory	2,3%	4,0%
Nozzle - brush	2,5%	6,1%
Mounting system (wall)		4,5%
Small wheels		4,1%
Fixation bolt		4,8%
Rechargeable battery		40,1%

*** similar or potentially compatible spare part**

A total of 7 items could be found as consumer consumables for the assessed upright VC. When searching for spare parts offered by third party providers, 4 additional parts could be identified based on the model reference number.

It is important to highlight that the availability of some of the often replaced item parts could not be identified as purchasable by consumers during our research However, for professional repair organisation all spare parts are made available by manufacturer.

The table below summarizes the consumer price of available spare. All spare parts made available by manufacturer have a low cost (<5% of catalogue price).

6.4 Repairability assessment – Case study 2a

- ***Product identification***

<u>Ease of identification</u>

Brand and model version are available for identification on the product. The GTIN barcode can only be found on the outer packaging box.

<u>Option selected:</u> Brand and unique model version reference at least point 10.*
<u>Score:</u> 5/10

<u>Accessibility of identification</u>

No disassembly is necessary in order to identify the product.

<u>Option selected:</u> Accessible after manual operation without disconnecting components
<u>Score:</u> 10/10

<u>Robustness of identification</u>

Unique product identification information, such as the model version, is labelled onto the lower case of the product. Other information such as brand name and product functional option are engraved on the product.

<u>Option selected:</u> All or part of the product identification information is included on removable labels e.g. glued
<u>Score:</u> 2/5

<u>Availability of identification support</u>

All customers can always contact the manufacturer's helpdesk via the different touchpoints. The manufacturer has indicated that full technical support is guaranteed within the warranty period and most technical support for customers is expected within 2-5 years after purchase.

<u>Option selected:</u> Technical support from manufacturer available for product identification for at least 10 years after last production*
<u>Score:</u> 5/5

Accessibility of identification support

Local service is provided on the website of the manufacturer, through a local call center, chat and email. The call center is also available on Saturday and local calling rates apply. Possible locations of model number is graphically depicted on the website of the manufacturer. In addition, the manufacturer offers the consumers the possibility to register their products. When the product is registered, the product identification will not be an issue as long as the consumer remembers the email linked to his account.

Option selected: Toll-free or web-based support available for product identification.
Score: 5/5

- ***Failure diagnostic***

Instructions for problem identification – content

The user manual is provided in hard copy with purchase and is also available online on the website of the manufacturer. The user manual contains a generic checklist for vacuum cleaners of identified root causes for common failures as well as safety measures. On the website, some troubleshooting questions are available, related to the VC not starting, unusual heating or noise, dirt build up inside VC and wrong indication of full dust containers. However, most of them will redirect you to the support service. Safety measures are included in the user manuals, but limited to proper usage.

The service manual, that is only available to registered repairers, includes an electrical diagram of the control board and of the remote control. It does not include further information related to failure diagnostics.

For consumers:
Option selected: Repair instruction includes the following elements:
- safety measures
*- (check)list of identified root causes for common failures**
Score: 2/10

For professional repairers:
Option selected: Repair instruction includes the following elements:
- safety measures
- fault diagnostic advice: (check)list of identified root causes for common failures and troubleshooting tree*
- test method to check working condition of priority part
- complete list of error codes and required repair actions, if applicable
- diagrams of the Printed Circuit Board, if applicable
- fault detection software , if applicable
Score: 10/10

Product designed for easy failure detection

The vacuum cleaner does not have an interface available for failure detection. Failure diagnostics for this product type is mostly done through a decision tree. Therefore, this criterion is not relevant for a vacuum cleaner. However a dust container saturation indicator is included which can provide information on the need for bag or filter replacement. Although filter replacement is not seen as a technical failure by manufacturers, it is quoted by users as a frequent problem with VCs.

Option selected: *Visually intuitive interface: Cause of failure can easily be established due to implemented features in the product (software) design. There is no need for additional supporting documentation or software*
Score: *10/10*

Availability of failure diagnostic support

All customers can always contact the manufacturer via the different touchpoints. The manufacturer has indicated that full technical support is guaranteed during warranty period. Typical warranty period is set to 2 years but for specific components (such as the motor for VCs) additional warranty is provided if the product is registered. When the invoice is successfully uploaded a contract number is issued. For repair services after the warranty period, the manufacturer will redirect the customer to approved third party repair services.

Option selected: *Technical support from manufacturer available for product identification for at least 10* years after last production*
Score: *5/5*

Accessibility of failure diagnostic support

Customer service can be reached through a local call center, chat and email. A distinction is made based on product category. The support system will not support the problem identification process (which is done by the third party contracted repair center) but will direct the customer to authorized repair centers. The goal is not to support customers or independent repair centers to (self)-repair their products.

Repair services after the warranty period will most likely entail repair costs for the customers (even for the diagnose). Although a repair action/demand can easily be initiated through the portal, no direct contact information of repair centers is provided in Belgium. The repair center is supposed to contact the customers in due time (no specific time frame is provided). The repair center typically contacts the customer the following working day via email with instruction to send the failed product. The email also contains a link to detailed price information for their service (when the product is out of warranty). A VC would fall in the 'small appliance' category for which an estimated cost of 70 euro applies. If the repair cost is higher, a quote will be sent to the customer before further action is taken. If the customer decided not to repair a 'diagnose fee' will still apply. The site does not mention how much this fee is.

Option selected: *Local fee contact available for failure diagnostic.*
Score: *2/5*

- ***Disassembly and reassembly***

Disassembly instructions – content & availability

The user manual does not contain any information related to disassembly and reassembly. Some maintenance information is given for replacing filters and cleaning hose and dust container.

Some disassembly and reassembly advice is provided in the service manual that is not available for consumers. However, the information in the service manual is not provided in a standard format and limited structure is provided to the instructions. Nonetheless, the provided information is considered to be essential information before engaging in disassembly activities of the VC. The service document also includes an exploded view with indication of connectors and available spare parts list. Although the general type of connector (screws) is indicated, the required tools are not mentioned (specific type and size).

For consumers:
Option selected: *Not Available*
Score: *0/10*

For registered repairers:
Option selected: *Disassembly instructions include the following elements:*
- exploded diagram (include minimum size)*
- list of connectors used & required tools
*- description of recommended disassembly steps to remove priority parts**
Score: *10/10*

Product designed for ease of disassembly

The average eDIM for partial disassembly is 5,4 min which represents 38% of the eDIM for total disassembly. When the failure rates for the product parts is taken into account, a weighted average for partial disassembly of about 3 min is calculated which represents only 20% of the eDIM for total disassembly.

Option selected: *Average ease of disassembly: average eDIM for partial disassembly represents between [15%-30%] of eDIM for total disassembly*
Score: *5/10*

Required tools for disassembly

A “normal” Torx T15 screwdriver (tool list B) with extension cannot be used since it does not fit in the smaller openings. Therefore a T15 screwdriver with a 14,5cm shank is required. This specific type of screwdriver is commercially available, but is not a common purpose tool. It can be ordered online on specialized websites, but is not available in most DIY-shops.

Option selected: *Priority part(s) can be replaced using specialized commercially available tools (from specific list B*)*
Score: *2/10*

Availability of technical support for disassembly and reassembly

Manufacturer has indicated that technical support lies between 2-5 years, typically around warranty period. For repair services after the warranty period, the manufacturer will redirect the customer to approved third party repair services.

Option selected: *Technical support from manufacturer available for disassembly and reassembly for at least 10* years after last production*
Score: *5/5*

Accessibility of technical support for disassembly and reassembly

Customer service can be reached through a local call centre, chat and email. Technical support is provided through local call centres for which local contact information is available. As standard phone numbers are used, local calling rates are assumed. There is no direct contact with repair centres.

<u>Option selected:</u> Local fee contact available for disassembly and reassembly.
<u>Score:</u> 2/5

- ***Spare part replacement***

Purchase information for spare parts

On the manufacturer's site only 3 consumer replaceables are available for this model. No further information is provided for other spare parts by the manufacturer to the consumers.

Reference list of available spare parts, including reference numbers, is provided by the manufacturer in the service manual which is available for contracted third party repairers. This list includes 34 identified spare parts of which some spare parts are defined as an assembly including a number of 'sub-parts'. All spare parts are available to professional repairers.

For consumers:
<u>Option selected:</u> Information related to spare parts include the following elements:
- Information on spare parts supply (address, webshop)
<u>Score:</u> 5/10

For professional repairers:
<u>Option selected:</u> Information related to spare parts include the following elements:
- Information on spare parts supply (address, webshop)
- Spare part register including unique reference numbers of available spare parts.
<u>Score:</u> 10/10

Information for 3D printing - availability

No information regarding 3D printing of components is provided.

<u>Option selected:</u> Not available
<u>Score:</u> 0/2

Modular design of the product

The proposed list of key components in the previous section is used for assessing the modularity of the vacuum cleaner. The following components are defined as separate spare part:

- Motor
- Brushes/Nozzles
- Power cable
- Wheels

The remote control has been identified as a part that fails prematurely. Currently, it needs to be jointly replaced with the hose which is another priority part. Another priority part that could be considered for separate replacement are the carbon brushes of the motor which are known to known to fail prematurely.

<u>Option selected:</u> At least 75% (by count) priority parts can be replaced individually*
<u>Score:</u> 5/10

<u>Standardized design</u>

For some priority parts, generic spare parts can be used such as filters and motor. The same filter components are used in different VC models. However not all priority parts are standardized.

<u>Option selected:</u> A number of priority parts are standardized*
<u>Score:</u> 2/5

<u>Supply of spare parts - content</u>

The manufacturer provides a limited number of spare parts for this product to the consumer via its web shop. Some additional parts could be identified such as the hose and nozzle with third party suppliers. However the availability to consumers of the wheels, electronic boards, casing parts and power cable could not be confirmed. The reasons for this may be twofold. First, this is a rather new model that was released in the summer of 2017 which means that the sold items are still in the warranty period and the demand for spare part is still limited. Second, repairs that are considered to be unsafe for layman may be discouraged by the manufacturer.

For professional repairers all spare parts listed in the service manual can be accessed.

For consumers:
<u>Option selected:</u> Compatible spare parts for priority parts are limited available for this product 50%* (by count)*
<u>Score:</u> 2/5

For professional repairers:
<u>Option selected:</u> Compatible spare parts for priority parts are widely available for this product 100% * (by count)*
<u>Score:</u> 5/5

<u>Supply of spare parts - availability</u>

Based on the information received from the manufacturer, the average availability of spare parts is estimated between 5 and 7 years after the last production date. Decision on the number of items kept in stock by the manufacturer is taken by the forecasting team depending on previous demand for specific spare parts.

<u>Option selected:</u> Mid-term availability of spare parts availability for at least 5 years after last production*
<u>Score:</u> 2/5

<u>Supply of spare parts - cost</u>

On average priority spare parts consumer price is 14% of catalogue price for new product.

Authorized repair centers have access to all listed spare parts and have specific commercial conditions based on their turnover. On average priority spare parts price for authorized repairers is <5% of catalogue price for new product.

For consumers:
<u>Option selected:</u> Average consumer price of available spare parts is between 10% and 20% of catalogue price of the product (20% included)*
<u>Score:</u> 2/10

For professional repairers:
<u>Option selected:</u> Average consumer price of available parts is less or equal to 5% of catalogue price*
<u>Score:</u> 10/10

- ***Restoring to working condition***

<u>Instructions for reconditioning of product</u>

No dedicated factory settings are implemented in the design and no instructions are included in the user manual or service document related to restart of the product after repair. However this is not relevant for this product type as no specific reset action is required.

<u>Option selected:</u> Repair instruction includes procedure to reset to default / factory settings and restore product to working condition, as appropriate.
<u>Score:</u> 5/5

<u>Product designed for ease of restoring to working condition after repair</u>

There is no need for an external specialized device to restore the vacuum cleaner to working condition after repair.

<u>Option selected:</u> Product resetting can be done without intervention with an external / specialized device.
<u>Score:</u> 2/2

<u>Technical support for reconditioning – accessibility</u>

Customer service can be reached through a local call centre, chat and email. Technical support is provided through local call centres for which local contact information is available. As standard phone numbers are used, local calling rates are assumed. There is no direct contact with repair centers.

<u>Option selected:</u> Local fee contact available for reconditioning.
<u>Score:</u> 2/5

6.5 Repairability assessment – Case study 2b

- ***Product Identification***

<u>Ease of identification</u>

Brand and model version are available for identification onto the product. The GTIN barcode can only be found on the outer packaging box.

<u>Option selected</u>: Brand and unique model version reference at least point 10.*
<u>Score</u>: 5/10

<u>Accessibility of identification</u>

No disassembly is necessary in order to identify the product.

<u>Option selected:</u> Accessible after manual operation without disconnecting components
<u>Score:</u> 10/10

<u>Robustness of identification</u>

Unique product identification information, such as the model version, is labelled onto the lower case of the product. Other information such as brand name and product functional option are engraved on the product.

<u>Option selected:</u> All or part of the product identification information is included on removable labels e.g. glued
<u>Score:</u> 2/5

<u>Availability of identification support</u>

All customers can always contact the manufacturer via the different touchpoints. The manufacturer has indicated that full technical support is guaranteed within the warranty period and most technical support for customers is expected within 2-5 years after purchase.

<u>Option selected:</u> Technical support from manufacturer available for product identification for at least 10 years after last production*
<u>Score:</u> 5/5

<u>Accessibility of identification support</u>

Local service is provided on the website of the manufacturer, through a local call center, chat and email. The call center is also available on Saturday and local calling rates apply. Possible locations of model number is graphically depicted on the website of the manufacturer. In addition, the manufacturer offers the consumers the possibility to register their products. When the product is registered, the product identification will not be an issue as long as the consumer remembers the email linked to his account.

<u>Option selected:</u> Toll-free or web-based support available for product identification.
<u>Score:</u> 5/5

- ***Failure Diagnostics***

<u>Instructions for problem identification – content & availability</u>

The user manual contains a checklist of identified root causes for common failures as well as safety measures. On the website, some additional troubleshooting questions are available, but limited to motor, filter maintenance and battery. In the end, most of them will redirect you to the support service. Safety measures are included in the user manuals, but limited to proper usage.

The service manual, that is only available to contracted third party repairers, includes a circuit diagram of the control board. There is no additional guidance on failure diagnostics.

For consumers:
<u>Option selected:</u> Repair instruction includes the following elements:
- *safety measures*
- *(check)list of identified root causes for common failures**

<u>Score:</u> 2/10

For professional repairers:
<u>Option selected:</u> Repair instruction includes the following elements:
- *safety measures*
- *fault diagnostic advice: (check)list of identified root causes for common failures* and troubleshooting tree*
- *test method to check working condition of priority part*
- *complete list of error codes and required repair actions, if applicable*
- *diagrams of the Printed Circuit Board, if applicable*
- *fault detection software , if applicable*

<u>Score:</u> 10/10

<u>Product designed for easy failure detection</u>

The vacuum cleaner does not have an interface available for failure detection. Failure diagnostics for this product type is mostly done through a decision tree. Therefore, this criterion is not relevant for a vacuum cleaner. However, a battery depletion indicator to warn the user when the battery needs to be charged is included.

<u>Option selected:</u> Visually intuitive interface: Cause of failure can easily be established due to implemented features in the product (software) design. There is no need for additional supporting documentation or software
<u>Score:</u> 10/10

<u>Availability and accessibility of failure diagnostic support</u>

The technical support offered by the manufacturer is the same for all products. Please refer to previous chapter for more information.

<u>Option selected:</u> Technical support from manufacturer available for product identification for at least 10 years after last production*
<u>Score:</u> 5/5

<u>Option selected:</u> Local fee contact available for failure diagnostic.
<u>Score:</u> 2/5

- ***Disassembly and Reassembly***

<u>Disassembly instructions – content</u>

The user manual does not include any specific disassembly/reassembly information related to repair. It does include information to remove the rechargeable battery at end of life (not for repair) and an exploded view.

The service manual, that is not available to consumers includes an more detailed exploded view diagram but no additional guidance for disassembly/reassembly, connection types or tool list is included.

<u>Option selected:</u> Disassembly instructions include the following elements:
- exploded diagram (include minimum size)*
<u>Score:</u> 2/10

<u>Product designed for easy of disassembly</u>

The average eDIM for partial disassembly is almost 5 min which represents 17% of the eDIM for total disassembly. When the failure rates for the product parts is taken into account, a weighted average for partial disassembly of about 6,5 min is calculated which represents 22% of the eDIM for total disassembly

<u>Option selected:</u> Average ease of disassembly: average eDIM for partial disassembly represents between [15%-30%] of eDIM for total disassembly
<u>Score:</u> 5/10

<u>Required tools for disassembly</u>

The only tools required are Philips PH1 and PH3, which are on tool list A.

<u>Option selected:</u> Priority part(s) can be replaced using only common general purpose tools (from specific list Annex A)*
<u>Score:</u> 5/10

<u>Availability and accessibility of technical support for disassembly and reassembly</u>

The technical support offered by the manufacturer is the same for all products. Please refer to previous section for more information.

<u>Option selected:</u> Technical support from manufacturer available for disassembly and reassembly for at least 10 years after last production*
<u>Score:</u> 5/5

<u>Option selected:</u> Local fee contact available for disassembly and reassembly.
<u>Score:</u> 2/5

- ***Spare Parts***

<u>Purchase information for spare parts</u>

Only 7 consumer replaceables are listed for this model on the manufacturer website.

Reference list of available spare parts, including reference numbers, is provided by the manufacturer in the service manual which available for all professional repairer. This list includes 17 identified spare parts of which some spare parts are defined as an assembly of a number of ‘sub-parts’.

For consumers:
<u>Option selected:</u> Information related to spare parts include the following elements:
- *Information on spare parts supply (address, web shop)*

<u>Score:</u> 5/10

For professional repairers:
<u>Option selected:</u> Information related to spare parts include the following elements:
- *Information on spare parts supply (address, web shop)*
- *Spare part register including unique reference numbers of available spare parts.*

<u>Score:</u> 10/10

<u>Information for 3D printing - availability</u>

No information regarding 3D printing of components have been provided.

<u>Option selected:</u> Not available
<u>Score:</u> 0/2

<u>Modular design of the product</u>

Not all priority parts can be individually replaced. The electric motor needs to be jointly replaced together with the turbine.

<u>Option selected:</u> At least 75% (by count) priority parts can be replaced individually*
<u>Score:</u> 5/10

<u>Standardized design</u>

For some priority parts, generic spare parts can be used such as filters and motor. The same filter components are used in different VC models. However not all priority parts are standardized.

<u>Option selected:</u> A number of priority parts are standardized*
<u>Score:</u> 2/5

<u>Supply of spare parts - content</u>

The manufacturer provides only a number of spare parts for this product to consumers. For professional repairers all spare parts listed in the service manual can be accessed.

For consumers:
<u>Option selected:</u> Compatible spare parts for priority parts are limited available for this product 50%* (by count)*
<u>Score:</u> 2/5

For professional repairers:
<u>Option selected:</u> Compatible spare parts for priority parts are widely available for this product 100% * (by count)*
<u>Score:</u> 5/5

Supply of spare parts – availability

Based on information provided by the manufacturer, the average availability of spare parts is estimated between 5 and 7 years after last production date. Decision on the number of items kept in stock by the manufacturer is taken by the forecasting team depending on previous demand for specific spare parts.

Option selected: Mid-term availability of spare parts availability for at least 5 years after last production*
Score: 2/5

Supply of spare parts – cost

On average priority spare parts consumer price is 11,7% of catalogue price for new product.

Professional repair centers have access to all listed spare parts and have specific commercial conditions based on their turnover. On average priority spare parts price for professional repairers is around 6% of catalogue price for new product.

For consumers:
Option selected: Average consumer price of available spare parts is between 10% and 20% of catalogue price of the product (20% included)*
Score: 2/10

For professional repairers:
Option selected: Average consumer price of available parts is between 5 and 10% of catalogue price (10% included)*
Score: 5/10

- ***Restoring to working condition***

Instructions for restoring to working condition of product

No dedicated factory settings are implemented in the design and no instructions are included in the user manual or service document related to restart of the product after repair. However this is not relevant for this product type as no specific reset action is required.

Option selected: Repair instruction includes procedure to reset to default / factory settings and restore product to working condition, as appropriate.
Score: 5/5

Product designed for ease of restoring to working condition after repair

There is no need for an external specialized device to restore the vacuum cleaner to working condition after repair.

Option selected: Product resetting can be done without intervention with an external / specialized device.
Score: 2/2

Technical support for reconditioning – accessibility

Customer service can be reached through a local call center, chat and email. Technical support is provided through local call centres for which local contact information is available. As standard phone numbers are used, local calling rates are assumed. There is no direct contact with repair centres.

Option selected: *Local fee contact available for reconditioning.*
Score: *2/5*

6.6 Repairability assessment results

- ***Overview of criteria scores – Case study 2a – Canister VC***

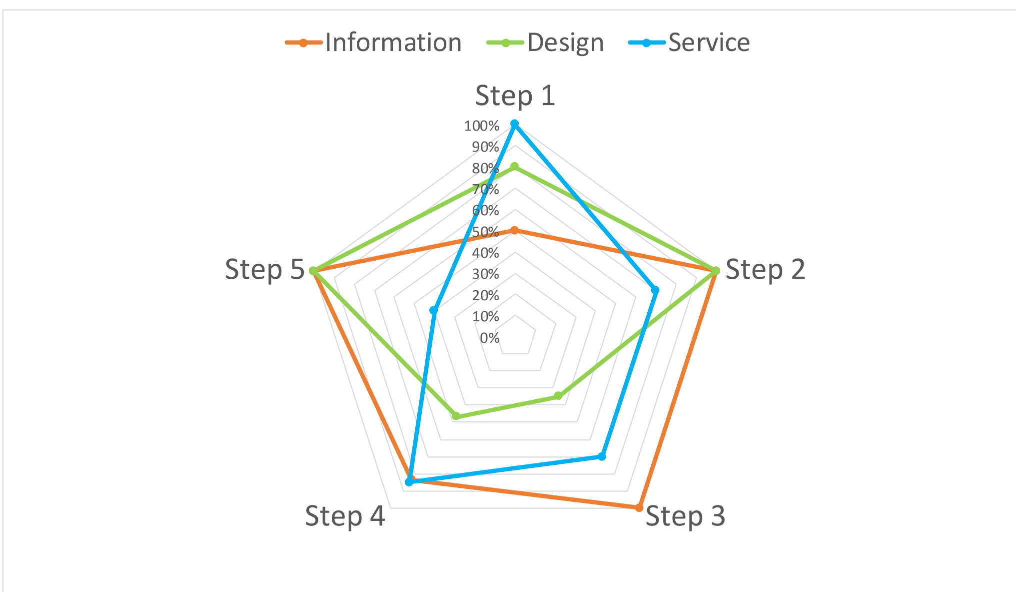
	Nr	Criterion description	Score Consumer	Score Repairer	Max
Repair Step 1: Product identification	1.1	Ease of identification	5		10
	1.2	Accessibility of identification	10		10
	1.3	Robustness of identification	2		5
	1.4	Availability of identification support	5		5
	1.5	Accessibility of identification support	5		5
Repair Step 2: Failure diagnostic	2.1	Instructions for problem identification - content	2	10	10
	2.2	Product designed for easy failure detection	10		10
	2.3	Availability of failure diagnostic support	5		5
	2.4	Accessibility of failure diagnostic support	2		5
Repair Step 3: Disassembly and reassembly	3.1	Disassembly instructions - content	0	10	10
	3.2	Product designed for ease of disassembly	5		10
	3.3	Required tools for disassembly	2		10
	3.4	Availability of technical support for disassembly and reassembly	5		5
	3.5	Accessibility of technical support for disassembly and reassembly	2		5
Repair Step 4: Spare part	4.1	Information for spare parts	5	10	10
	4.2	Information for 3D printing of spare parts	0		2
	4.3	Modular design of the product	5		10
	4.4	Standardized design	2		5
	4.5	Supply of spare parts - content	2	5	5
	4.6	Supply of spare parts - availability	2		5
	4.7	Supply of spare parts - cost	2	10	10
Repair Step 5: Resetting to working condition	5.1	Instructions for reconditioning of product	5		5
	5.2	Product designed for ease of restoring to working condition after repair	2		2
	5.3	Technical support for reconditioning - accessibility	2		5

- ***Summary: Final Score on Repairability – professional repairer – Case 2a canister VC***

	Maximum scores					
	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	10	10	10	12	5	47
Design	15	10	20	15	2	62
Service	10	10	10	20	5	55
	35	30	40	47	12	164

	Achieved assesed product scores					
	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	5	10	10	10	5	40
Design	12	10	7	7	2	38
Service	10	7	7	17	2	43
	27	27	24	34	9	121

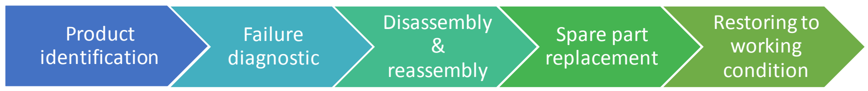
	Repairability score					
	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	50%	100%	100%	83%	100%	85%
Design	80%	100%	35%	47%	100%	61%
Service	100%	70%	70%	85%	40%	78%
	77%	90%	60%	72%	75%	**74%**



- ***Overview of criteria scores – Case study 2b – Upright VC***

	Nr	Criterion description	Score Consumer	Score Repairer	Max
Repair Step 1: Product identification	1.1	Ease of identification	5	5	10
	1.2	Accessibility of identification	10	10	10
	1.3	Robustness of identification	2	2	5
	1.4	Availability of identification support	5	5	5
	1.5	Accessibility of identification support	5	5	5
Repair Step 2: Failure diagnostic	2.1	Instructions for problem identification - content	2	10	10
	2.2	Product designed for easy failure detection	10	10	10
	2.3	Availability of failure diagnostic support	5	5	5
	2.4	Accessibility of failure diagnostic support	2	2	5
Repair Step 3: Disassembly and reassembly	3.1	Disassembly instructions - content	2	2	10
	3.2	Product designed for ease of disassembly	5	5	10
	3.3	Required tools for disassembly	5	5	10
	3.4	Availability of technical support for disassembly and reassembly	5	5	5
	3.5	Accessibility of technical support for disassembly and reassembly	2	2	5
Repair Step 4: Spare part	4.1	Information for spare parts	5	5	10
	4.2	Information for 3D printing of spare parts	0	0	2
	4.3	Modular design of the product	5	5	10
	4.4	Standardized design	2	2	5
	4.5	Supply of spare parts - content	2	5	5
	4.6	Supply of spare parts - availability	2	2	5
	4.7	Supply of spare parts - cost	2	5	10
Repair Step 5: Resetting to working condition	5.1	Instructions for reconditioning of product	5	5	5
	5.2	Product designed for ease of restoring to working condition after repair	2	2	2
	5.3	Technical support for reconditioning - accessibility	2	2	5

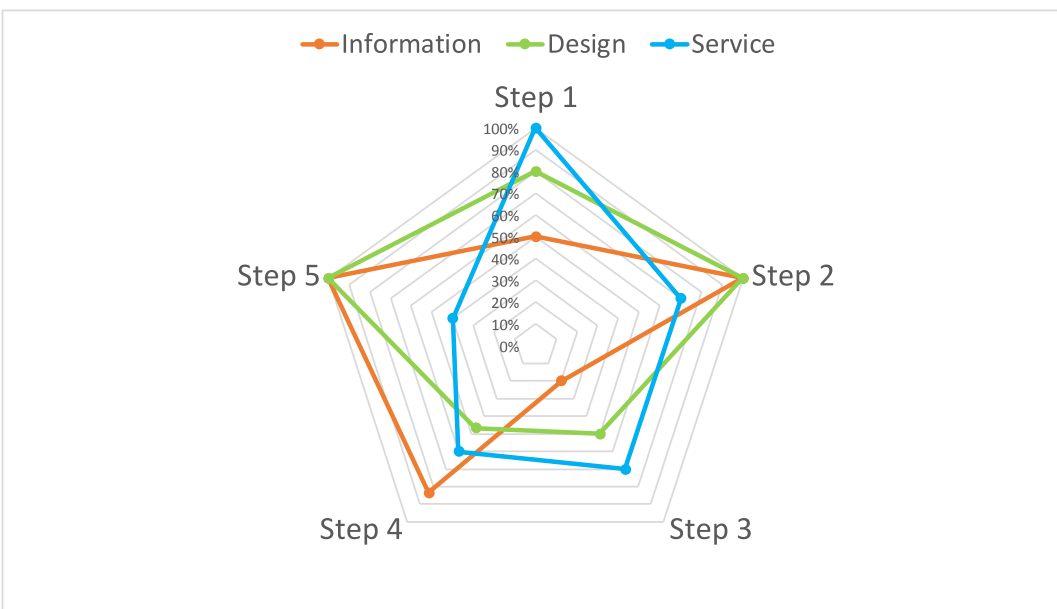
- ***Summary: Final Score on Repairability – Professional repairer - Case 2b upright VC***



Maximum scores	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	10	10	10	12	5	47
Design	15	10	20	15	2	62
Service	10	10	10	20	5	55
	35	30	40	47	12	164

Achieved assesed product scores	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	5	10	2	10	5	32
Design	12	10	10	7	2	41
Service	10	7	7	12	2	38
	27	27	19	29	9	111

Repairability score	Step 1	Step 2	Step 3	Step 4	Step 5	
Information	50%	100%	20%	83%	100%	68%
Design	80%	100%	50%	47%	100%	66%
Service	100%	70%	70%	60%	40%	69%
	77%	90%	48%	62%	75%	**68%**



Chapter 7: Lifecycle costing

7.1 Introduction to Lifecycle costing (LCC)

Providing monetary operating costs to the use of appliances dates back to 1987, when first mentioned by Lund (51). Since then, new approaches have emerged and improved the life cycle costs (LCC) calculations. The LCC is especially useful for the assessment of the total cost of ownership of an appliance, taking into account the costs related to owning, operating and disposing the appliance. In addition, LCC is found an interesting tool to compare products with the same performance requirements. In these cases, LCC allows to select the most cost-effective option. Since 1987, the methodology has been applied to numerous different appliances (52), including vacuum cleaners and washing machines.

LCC must be distinguished from Life Cycle Assessments (LCA). Both concepts have common elements in their rationale, but they aim to quantify completely different aspects related to the purchase, and making use of a machine or appliances. On the one hand, LCA has a distinct environmental focus as it assesses the environmental impact associated with all stage of a product's service life (including extraction of material, production, use, disposal,…). On the other hand, LCC explicitly focusses on the monetary costs related to the purchase, use and disposal of a machine into account. Heijungs et al presented an attempt to unify LCC and LCA, but in general both concepts are calculated independently (53). Task 4 starts from a consumer point of view, and therefore adheres the LCC concept. This allows determining all costs a consumer will face following a purchase, the use, and disposal of either a vacuum cleaner or a washing machine. At present, the LCC methodology is applied by numerous official institutions, including the European Commission (54) or the International Organization for Standardization (55).

Different types of LCC have emerged, depending on three aspects:

- Type of costs taken into account: private costs and/or external (damage) costs.
- Detailed or aggregated data from one actor's perspective.
- Discounted to Net Present Value

The next section further details the methodology used in the present study.

7.2 Methodology used for LCC

This research reflects the traditional 'single end user' perspective. This implies that the private costs of the purchase, use and disposal are taken into account. Those costs are determined at aggregated level (distinction is made between the different contributing factors to the overall LCC), and the individual costs are discounted to Net Present Value (NPV).

Hence, this approach rules out the internalisation of environmental costs. The reason to do so is twofold. First, the consumer perspective is essential for research on repairability options as it is the individual consumer who decides whether his/her property should be repaired (neglecting the possibility of service-oriented leasing of machines and appliances, or multi-user use possibilities). In this philosophy (and in accordance with the 'tragedy of the commons' reasoning (56)), the external costs are often neglected, and only the directly attributable monetary costs are taken into account by the consumer. Second, to monetization of (environmental) externalities is a complicated activity (57) often leading to results incomprehensible to individual consumers, or prone to uncertainty.

- ***Private costs of ownership***

The research considers 3 appliances: a washing machine, an upright vacuum cleaner and a canister vacuum cleaner. Acquiring and using each of these appliances comes with appliance *i*-specific costs. More in particular, this research distinguishes three types of costs:

- Investment costs $I_{i,t}$
- Operational costs $O_{i,t}$
- Other costs $V_{i,t}$

In which the *t*-index provides the indication for time, i.e. the *n^th^* year of the service life of the appliance. Hence, each of the 3 cost categories is specified for each individual year of the service life. As such, the annual cost of ownership for appliance *i* equals the sum of the three cost categories, per year *t*. Each category of costs encompasses numerous specific costs (Table 20):

$$C_{i,t} = I_{i,t} + O_{i,t} + V_{i,t}$$

Table 20: Components per cost category

Category	Components
Investment costs $\boldsymbol{I_{i,t}}$	Purchase price
	Cost of delivery*
	Cost of installation and start-up*
	Cost of additional warranty contract
Operational costs $\boldsymbol{O_{i,t}}$	Energy usage
	Water usage*
	Service and maintenance*
	Safety check*
	Auxiliary components (filters, bags, detergent,…)*
Other costs $\boldsymbol{V_{i,t}}$	Taxes
	Disposal costs
	Residual value

NOTE - * indicates that these costs are appliance *i*-specific and only taken into account if applicable.

The monetary amount attributed to each individual cost is further explained in the case study description. For now, notice that those costs only apply in the situation in which an appliance is purchased, used and finally disposed at the end of its service life. The end of an appliance's total product service life typically follows a defect of the appliance, or in one of the appliance's parts. However, the end-user can opt for a repair of the appliance as well. In this case, the repair cost $R_{i,t}$ is added to the cost of ownership $C_{i,t}$:

$$R_{i,t} = \sum_{j} S_{i,j} + L_{i,j}$$

In which:

- $S_{i,j}$ = cost of spare part *j*, if needed. Those costs are assumed constant over time per spare part *j*, but will only occur if the part is broken in a specific year *n*.

- $L_{i,j}$ = labour costs, which depend upon the time needed to repair a defect to part *j*, or replace part *j.* The labour cost are assumed constant over time per defect to part *j*, but will only occur if the part is broken in a specific year *n.*

Notice that there is a likelihood, but not a certainty, that the individual parts break. Hence, if a part *j* does not break during the appliance's service life, $S_{i,j}$ and $L_{i,j}$ are set at zero for each year *n* and part *j* does not contribute to the cost of ownership.

Finally, if an appliance is broken but not repaired, the end consumer is assumed to replace the appliance. This research assumes that the broken appliances are replaced by identical appliances, at constant (but discounted, see next paragraph) prices. This could be a mere simplification of reality as the literature review demonstrates that due to the technical evolution hints appliances are assumed to become more efficient in terms of energy (and water) use in the long run. In addition, more efficient production techniques can result in a price decrease of the appliances in the long run. This research however neglects these possibilities because different scenario's (e.g. repair versus replace) will be analysed and compared. In order to allow meaningful comparison, this research at first stages assumes replacement by identical appliances.

- ***Net Present Value calculation***

This study opts for the discounting of future costs because of the presence and importance of the time element in this study. The goal of repairability is to prolong the total product service life of an appliance. In this context, the discounting of future costs is a prerequisite for the comparability of present and future costs. On the other hand, a longer time frame also complicates the discounting of costs. This is accounted for by the Monte Carlo simulation.

Regulatory or governmentally funded project evaluation guidelines recommend the use of a (social) discount rate of 4%. However, the literature review describes that 'the' discount rate does not exist [2]: different people will differently value future costs/revenues in relation to present costs/revenues depending on their personal preferences. In addition, the JRC study by Bobba, Ardente and Mathieux [8] allows the discount rate to vary between 3% and 5%.

Hence, a standard discount rate of 4% is assumed, but this discount rate is likely to vary over a given population of consumers. This provides additional arguments in favour of the Monte Carlo simulation of LCC of the appliances, in order to allow the discount rate to vary in between pre-set boundaries. This enables an assessment of the impact of variability in the discount rate on the LCC of an appliance.

The net present value for future costs is calculated by adding up al discounted future costs per year:

$$NPV_{i,n} = \sum_{t=0}^{n} \frac{C_{i,t}}{(1+d)^t}$$

With:

- NPV_i = Net Present Value of the cost of ownership of appliance *i.*

- i = type of appliance (washing machine, upright vacuum cleaner, canister vacuum cleaner).
- t = time indication varying between the present ($t = 0$) and the end of the service life of the appliances after *n* years ($t = n$).
- $C_{i,t}$ = annual costs of the purchase, use and disposal appliance *i* in year *t*, including the repair or replacement costs if necessary.
- d = discount rate.

In this rationale, the NPV_i represents the life cycle cost of appliance *i* with a service life of *n* years*:*

$$NPV_{i,n} = LCC_{i,n}$$

- ***Monte Carlo simulation***

As indicated in the literature review, a number of the parameters in the cost calculation are prone to variability throughout the service life of an appliance. For this reason, this research does not calculate one single $LCC_{i,n}$ for appliance *i* with fixed parameter values*.* Instead a Monte Carlo simulation with 1500 rounds is initiated. As such, 1500 LCCs are calculated in different circumstances (i.e. for different parameter values, within pre-set boundaries).

At first stage, this research will assume homogenous behaviour among the population of end users. The variables which are allowed to vary at this stage are:

- The discount rate
- Energy usage
- Taxes
- Future prices
- (Non-) Occurrence of defects and failures

Prior to the Monte Carlo simulations, this research specifies a distribution with given expected value (mean) and standard deviation for each of those 4 parameters. For each of the 1500 LCC calculation rounds, a parameter value will be randomly drawn out of the pre-set distribution. Once the 1500 calculation rounds are finalised, a mean LCC can be determined for appliance *i*, as well as an analysis of the contribution of each parameter's variability to the LCC's variability. Note that this attributes more weight to the more likely expected values (the means) as they occur more frequently in comparison to the less likely parameter values. The following paragraphs explain the assumptions per parameter, Table 21 provides an overview of these specifications.

- ***Discount rate***

Based on literature review an average discount rate of 4% is assumed for this study. However, Deutsch explains that 'the' discount rate does not exist, and that the discount rate is individual-dependent (52). Also Bobba et al argue in favour of a discount rate between 3% and 5% (58). For this reason, a normal distribution with a mean of 4% and a 95% confidence interval between 3% and 5% is specified for the assumed discount rate.

- ***Energy usage***

For washing machines, the reported energy usage is based upon cycles in the eco-mode (i.e. energy efficient washing cycles) only. However, the more high-speed and conventional modes are expected to be more often selected. The two latter modes consume more energy in comparison to the eco-mode. The energy use of conventional washing rounds is 30% above the energy use of washing rounds in the eco-mode. In addition, variability in energy use also follows the frequency a household makes use of its appliance (washing machines or vacuum cleaners). Not every household will use their appliances as often as the 'average' household.

For those reasons, the mean energy consumption for washing machines is set at 15% above the reported energy requirements. Hence in between the eco- and the conventional washing mode. Subsequently, a standard deviation of 10% of the mean value is chosen, but a lower value is set at the reported eco-mode energy consumption (attributing more weight to this level of energy consumption). Also for the vacuum cleaners, a normal distribution is specified with a mean equalling the reported energy consumption, and standard deviation of 10% of the mean value.

- ***Taxes***

Taxes are not likely to vary. However, this study is conducting for appliances sold in Belgium, the Netherlands or Luxemburg. The Value Added Taxes (VAT) in those respective countries varies from 21%, 21%, and 17% respectively. For this reason, we also allow the VAT to vary in this research. On the downside, this is not very close to reality. However, this does allow us to analyse the impact of changes in the applied VAT tariff on the end users' LCC. A normal distribution with mean of 20% and standard deviation of 2% is chosen.

- ***Future prices***

According to EUROSTAT, the prices of consumer goods are expected to increase by 1,37% per year in future. However, this prediction is prone to numerous externalities and can therefore not be taken for granted. Variability in the future price evolution is introduced by the specification of a normal distribution with mean equal to 1,37%, and a standard deviation of 0,14%.

Table 21: Introducing variance in the Monte Carlo simulation

Parameter	Type of distribution	Mean	St. Dev	Remark
Discount rate	Normal	4%	0,2	95% Confidence Interval: [3%, 5%]
Energy usage	Normal	15% above reported energy use	10% of mean energy use	Minimum is set at reported energy use (=energy use during eco-mode)
Taxes	Normal	20%	2%	95% Confidence Interval: [17%, 23%]
Future prices	Normal	1,37%	0,14%	95% Confidence Interval: [1,14%, 1,60%]

- ***(Non-) Occurrence of defects and failures***

This research's Monte Carlo simulation introduces a likelihood for defects in the assessed appliances throughout their total product service life. This likelihood is based upon the analysis found in literature (36).

The likelihood of a failure or mal-functioning of an appliance provides no information on the cause of the failure. The cause of failure is taken from literature for washing machines and from data collected for this project for vacuum cleaners as described in previous chapters of this report.

By linking the likelihood of a failure occurring and the distribution of possible cause for the failure, the Monte Carlo simulation can take the likelihood of a defect for individual parts of the washing machine and the vacuum cleaner into account. In this rationale, each part is accompanied by a likelihood of a defect, but this defect must not necessarily manifest itself. Likewise, it is unlikely but possible that a washing machine or vacuum cleaner is not confronted by any defect whatsoever during the analysed period. In case of malfunctioning appliances, the consumer can on the one hand decide to dispose and replace the appliance. On the other hand, the consumer can also opt for a reparation of the appliance. Both options are further explained in the two following chapter.

- ***Costs for repair versus cost of disposal and replacement***

In case of a defect or malfunctioning appliance, the end user can decide to either repair, or alternatively dispose and replace the appliance. Different costs are associated to both options, and the costs related to both options differ per type of appliance. This is explained in the first two sections of this section.

Finally, this section also touches upon the behavioural aspects related to the repair option from a consumer point of view.

Replacement

In case a consumer does not repair a defect or malfunctioning appliance, it is assumed that the appliance is disposed and replaced. The replacement of the appliance comes with the cost of acquiring the same appliance again, against its purchase price. The purchase price is allowed to increase or decrease according to the price evolution (See Table 22). In order to account for the time element in this research, the full purchase price of the replacement is not necessarily taken into account in case different scenarios are compared. For reasons of comparison, the service life of the appliance in the repair scenario is used as benchmark. In case the appliance had to be replaced during this service life, only the proportion of the costs for the new appliance which corresponds attributable service life is taken into account. This is visualised in Figure 22.

If applicable, the purchase price is augmented with the cost of an additional warranty and the delivery and start-up costs (in case of the washing machine). The disposal costs are set at zero for both vacuum cleaners and washing machines. It is assumed that consumers can bring their (electronic) waste to recycling parks in Belgium, the Netherlands and Luxembourg free of charge. Hence, no monetary costs are attributed to the disposal of the appliance. In addition, this research does not introduce a monetary equivalent to the transaction costs related to the disposal (e.g. the effort to look up what type of waste can be brought to the recycling park, the time needed to transport the appliances,…) as those transaction costs are likely to differ too much across the consumers. The fact that consumers can bring the appliances to recycling parks free of charge does not imply that the disposal of appliances via recycling parks involves no cost. However, the consumer’s part of the costs related to the gathering and processing of appliances via recycling parks is already accounted for in the purchase price of the appliance. In Belgium this for example occurs through the 'Recupel contribution' (i.e. 1 euro on top of the consumer price, to be paid at the acquisition of a vacuum cleaner, or the washing machine) which is part of the displayed consumer prices.

This research assumes no residual value is received for a non-operational or malfunctioning appliance.

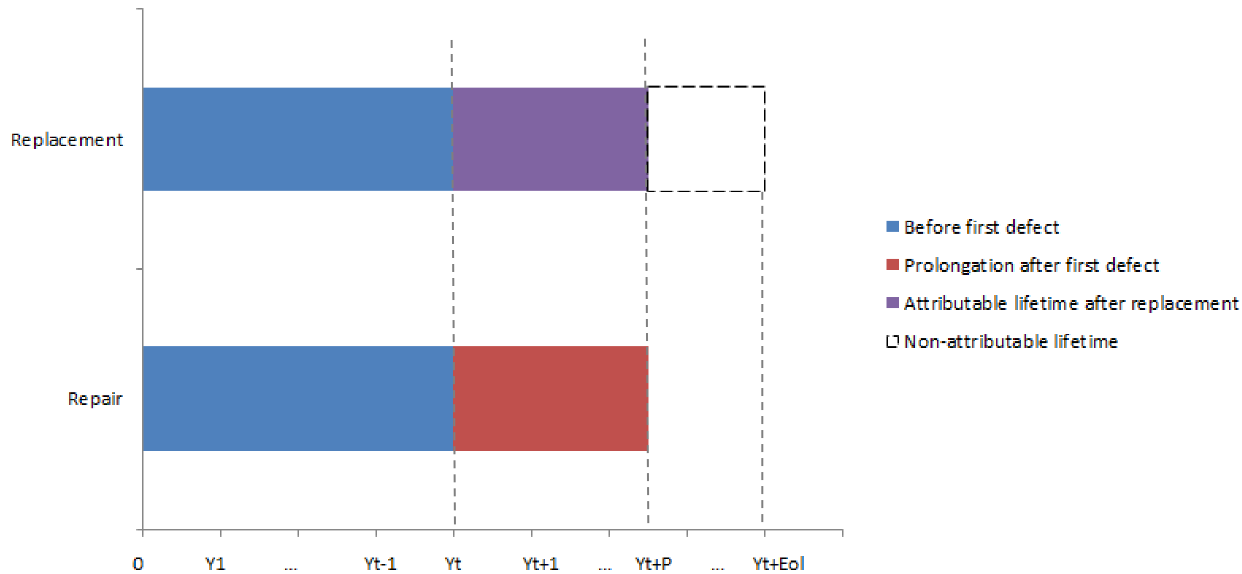


Figure 22: Timetable for attributable costs, with an assumed first defect in year Yt. In the 'Repair' scenario this results in a repair in year Yt, which prolongs the service life of the appliance by *P* years. In the 'Replacement' scenario this results in a replacement of the first appliance in year Yt, the new appliance reaches its end of service life after Eol years.

<u>Repair</u>

In case of a malfunctioning appliance, the specificities of the cause of the malfunction will determine the costs of the repair. In our simulations, the cost of repair consists of:

- Costs spare parts
- Labour cost repairmen (if applicable)
- Travel cost repairmen (washing machine)
- Shipping costs spare parts (vacuum cleaner)

For washing machines, the time needed to repair a specific part is presented in previous report of Task 3. A minimum amount of 89,99 euro is assumed as cost for repair, independently of the broken part. This amount includes the transport costs for the repairmen and accounts for repairs lasting less than 15 minutes. If a repair takes longer than 15 minutes, an additional 29,99 euro is added per 15 additional minutes. In addition, also the price of the spare part determines the price of the repair per cause of malfunction.

In the case of the vacuum cleaners, an average repair time needed of 30 min is assumed. The time required will again to some extent determine the cost of the repair. The time required for a repair is multiplied with an hourly cost of 59 euro. Broken vacuum cleaners are send for repair therefore shipping costs are assumed for the vacuum cleaner (6 euro for shipments below 5 kg). A double shipment to and from the repairmen is needed in case the vacuum cleaner is send for repair.

Behavioral aspects

The decision to repair or replace a product has received ample attention from a producer point of view, as producers often face this decision in the context of the (legal) warranty period (59–61), even with particular attention for the 'optimal' additional warranty to offer (62).

The decision to repair or replace appliances has received much less attention from a consumer point of view. Nevertheless, the consumer interest for the durability of household appliances is experiencing a revival in the context of increased concerns on waste generation. By applying LCC from a consumer point of view, this research provides an important contribution to literature in this context. Previous research worth mentioning is the work by McCollough (63). He explained that a higher (social) discount rate is more likely to result in a "throw-away society" compared to similar economies with lower social consumption discount rates. The set-up of this research's Monte Carlo allows to validate these findings by introducing variability in the individuals' consumption discount rates. In addition, McCollough (64) also listed some long-term trends which explain lower demand for repair services in the US.

The consumer decision to repair or replace a household appliance is complicated and depends on the individual consumer's appreciation of different factors and information. Cooper (65) for example mentioned the (lack of) information on the age of discarded products and the consumer attitudes to the products' service life spans. To tackle the latter issue, this research introduces two types of variation in the consumers' behavioural specification. At first, each consumer is expected to determine an individual cut-off point for repairs in time. I.e.: if the defect or malfunctioning of the appliance manifests itself too close to the expected end of the service life of the appliances, no money will be spend on the repair of the appliance. The appliance is replaced instead. This variability is introduced by specifying a normal distribution on the "safety margin" a consumer wishes to respect prior to the expected service life of the appliance. During the safety margin, no more repairs will occur, if needed. The mean safety margin is set at 2 years, and a standard deviation of 1 is chosen (while simultaneously introducing non-negativity for the safety margin).

Second, a consumer could lose faith in an appliance, if the appliance required multiple repairs throughout time. Hence, after a number of repairs he/she can decide not to repair the appliance again following a new defect or malfunctioning. Variability for this kind of behavioural aspects is again introduced by the specification of a log-normal distribution with a mean number of allowed repairs of 2, a minimum number of allowed repairs of 1, and a standard deviation of 1.

Finally, this research also considers the strategy to put a maximum amount to spend per repair. In this scenario, consumers will only repair their appliance in case the repair is not too costly (i.e. the maximum allowed repair cost allows repairs up to 15% of the purchase price).

Overview scenarios

A baseline scenario is simulated in which the device will be used and disposed after a malfunction. Alternatively, simulations are run different scenarios involving the repair of the device. First of all, a basic repair scenario is simulated in which the end-user unlimitedly repairs the device and opts for an extension of the mandatory 2-year legal warranty by an additional 3 years. This scenario is compared to the scenario in which the device is disposed & replaced. Additionally, alternative simulations are run for the different repair options. Three adaptions are made to the basic repair scenario: a) the number of repairs is analyzed, b) a maximum repair cost is introduced and c) the case without the purchase of the additional warranty is assessed. This results in 3 additional scenarios which are compared to each other, the basic repair scenario, and the dispose & replace scenario.

7.3 Results washing machine

At first, this chapter presents a baseline LCC analysis for a washing machine, without taking into account the possibility to repair the washing machine. Or alternatively dispose and replace the washing machine. Hence, this will only provide confined insights on the costs related to the ownership of a washing machine. Subsequently, also the possibilities to repair and replace will be introduced, and both possibilities will be compared to each other in terms of LCC. Finally, this chapter devotes special attention to the influencing factors (including the behavioural aspects, and the possibility for an extended warranty) on the washing machine's LCC.

- ***Life cycle cost - baseline***

Figure 23 presents the composition of the LCC for a washing machine. The overall mean LCC for the washing machine equals 2471 euro. This total LCC is composed out of the Net Present Value of all costs related to ownership of a washing machine. Notice that this is the mean LCC, out of 1500 LCC calculations, allowing different circumstances in terms of discount rate, energy usage, taxes, and future price evolutions. As such, for one of the 1500 individual LCCs, it might be possible to find differing compositions for the LCC. In general however, the purchase price of the washing machine is responsible for the main share of the LCC. In addition, the extended warranty, delivery and start-up, and the taxes on the sales price account for an aggregated share of 12% of the LCC. As such, all costs related to the purchase of the washing machine (i.e. before the machine becomes operational) account for 38% of the total LCC.

The costs related to the use of the washing machine account for 62% of the LCC. Those costs include the energy cost (24%), the detergent cost (18%), the water cost (15%), and the maintenance and safety check (5%). The later cost also includes the replacement of the filters. Finally, Figure 23 only presents the monetary costs of the LCC. Table 22 provides an overview of data input used to calculate the LCC for the washing machine.

Following the Monte Carlo simulation, this research finds an average service life of 10,79 years for the washing machines. As such, the annual LCC for the washing machine is 229 euro. It is useful to present the annual LCC, since the following parts of this research will present LCC calculations for scenarios with differing service lives. The annual LCC allows comparison (to some extent) between those different scenarios.

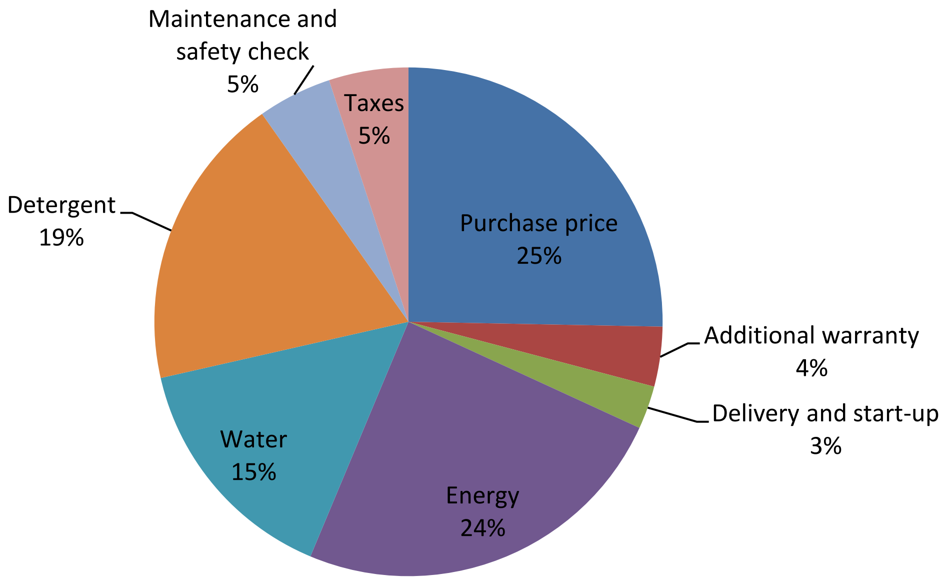


Figure 23: Composition of the LCC for washing machine
NOTE - This LCC assumes that the consumer opts for an extension of the legal warranty period. Only the monetary costs are taken into account.

Table 22: Overview of washing machine-specific costs and parameters, and accompanying sources

Type of cost	**Cost**	**Source**
Energy price	0,29 euro / kWh	EUROSTAT
Price of cold water	3,16 euro / m³	Weighted average for number inhabitants out of VMM (BEL), Vastelastenbond (NL), ministere de l'interieur et a la grande region (LUX)
Cost of delivery, installation and operational start-up	Not disclosed	/
Service and maintenance	Not disclosed	/
Detergent costs	0,2 euro / wash	(58)
Parameter	**Value**	**Source**
Legal warranty	2 years, no cost	European Consumer Centre
Additional warranty	3 additional years, costs 90 euro	Manufacturer's website

- ***Repair***

At first stage, we allow a consumer to repair a malfunctioning washing machine, independent from the type of defect. Figure 24 presents the composition of the LCC in case of restricted repairs. In this rationale, 'restricted' means that consumers adhere some kind of safety margin prior to the end of the expected service life in which no repairs will be allowed, and have a maximum number of repairs they accept within the service life of the appliance. This will be further explained in the following sections.

It becomes apparent that the mean service life of the washing machines in this scenario is extended to 16,51 years, almost 6 years longer than the initial service life calculated above. As a result of the extended service life, the total LCC increased to 3186,43 euro. However, the annual LCC has decreased until 193 euro. The operational costs has increased and account for higher shares of the LCC while the 'one-time' costs at acquisition of the washing machine contributes less. The (mean) cost of the repairs accounts for only 5% of the LCC. This appears to be a limited share, keeping in mind that the expenses on repairs are responsible for an extension of the service life by 72%.

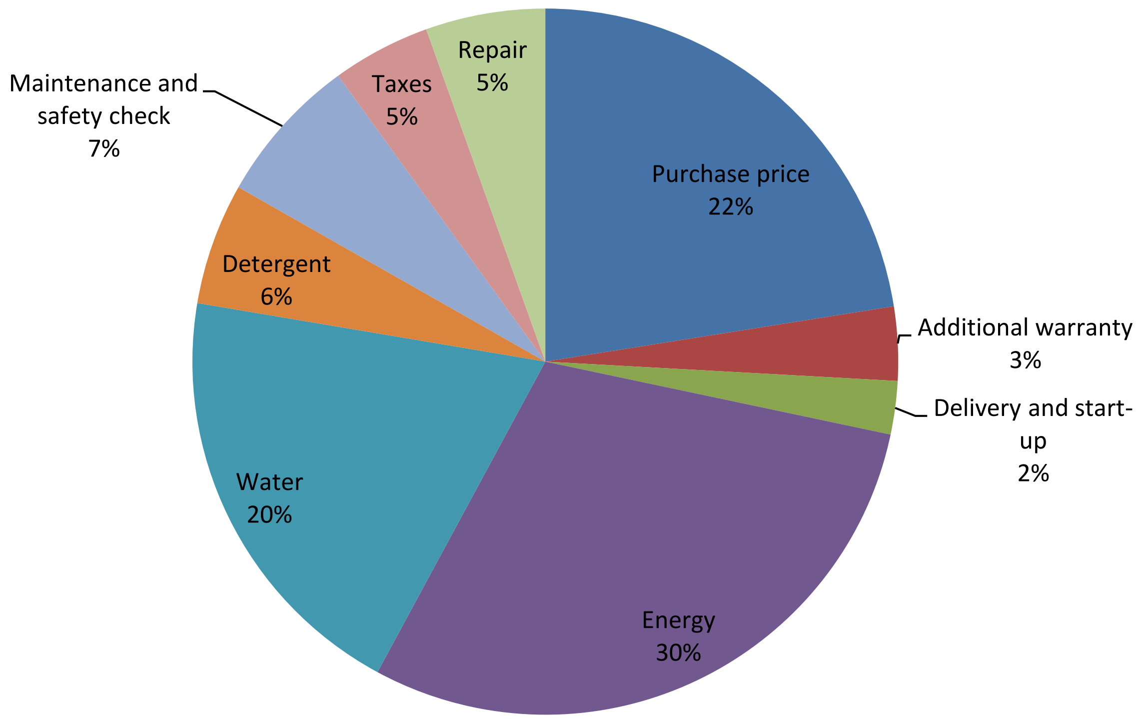


Figure 24: composition of the LCC of washing machine, in case of restricted repair

Behavioural aspects

On the one hand, this research introduces variance in terms of circumstances (discount rate, energy use, taxes, and price evolution). On the other hand, variance is introduced in terms of the consumers' behavioural aspects (safety margin and number of repairs allowed). The introduced variance for each of these parameters contributes to the variance in the LCC results, this is presented in Figure 25. The figure shows that increased energy use and price changes also increase the washing machine's LCC, with an energy use being the most important positively correlated parameter to LCC. The impact of the taxes (VAT) is only marginal, as they do not seem to contribute to the variance of the LCC. The discount rate is considerably negatively correlated to the LCC. This seems to confirm findings by McCollough [14] who claims that high discount rates lead to increased throw-away mentality. The lower the LCC, the lower the barrier to go for the easy replace option.

Concerning the behavioural aspect, Figure 25 demonstrates negative correlation for both parameters. Hence, applying a safety margin in order to decide whether an appliance should be repaired appears to be a good strategy. However, the contribution of the safety margin's variance only limitedly contributes to the LCC's variance in comparison to the variance in the number of repairs allowed. This number seems to be negatively correlated to the LCC.

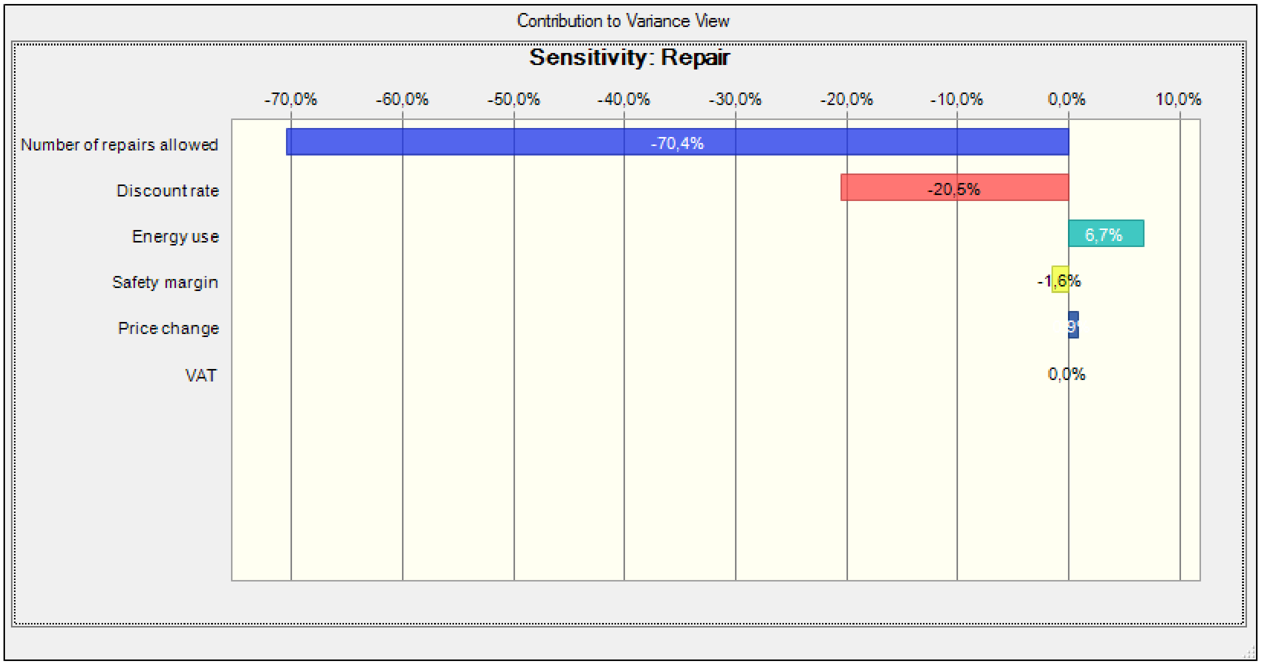


Figure 25: Contribution to variance in the LCC results (washing machine)

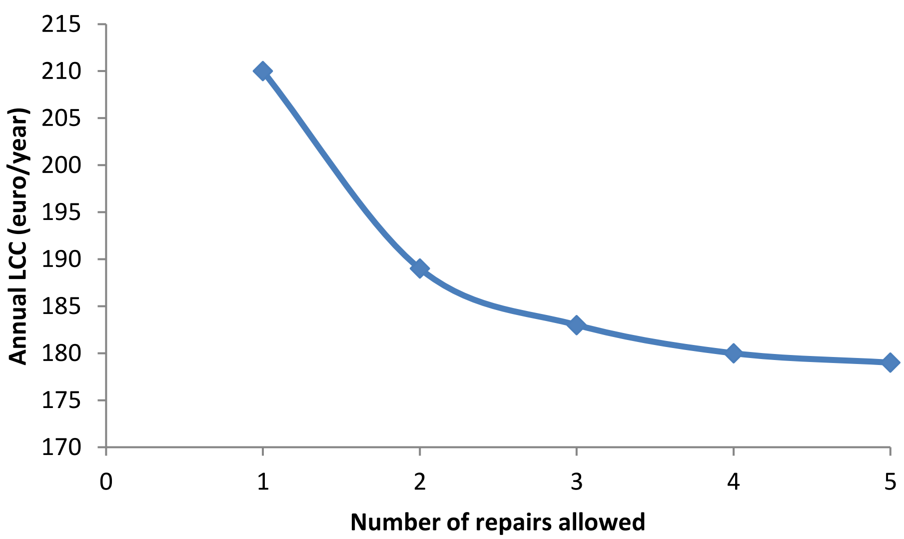


Figure 26: Mean annual LCC per predetermined number of repairs allowed
NOTE - each point in the scatter plot represents the mean of 1500 LCC calculations for each scenario of number of repairs allowed

Surprisingly, allowing more repairs decreases the cost of ownership of a washing machine. This is tested more thoroughly by rerunning the 1500 LCC calculations while accounting for the number of repairs allowed. This is done by eliminating the variance in the number of repairs allowed, and instead predetermining the number of repairs allowed. The results are presented in Figure 26. The figure demonstrates that the mean annual LCC decreases per additional number of repairs allowed. The decrease of the annual LCC is most apparent when a consumer allows two repairs instead of one repair, but the annual LCC keeps on decreasing afterwards as well. The rationale behind this observation could be that once you decide to invest in a repair of an appliance, you should also allow sufficient time in order to regain the investment through extended service life (possibly through follow-up repairs if needed).

Small repair

A third behavioural aspect concerns the amount to be spent on repairs. Some larger repairs (e.g. a lot of time is needed, or important parts are replaced) might seem disproportionally expensive in comparison to the purchase price of the washing machine. In these cases, consumers could refuse a repair as well. To further examine this type of preference, we introduced a consumer-specific maximum repair cost (per repair). Also for this additional parameter we introduced variance for the Monte Carlo simulation. A log-normal distribution is constructed for the maximum cost per repair, with mean of 100 and standard deviation of 10.

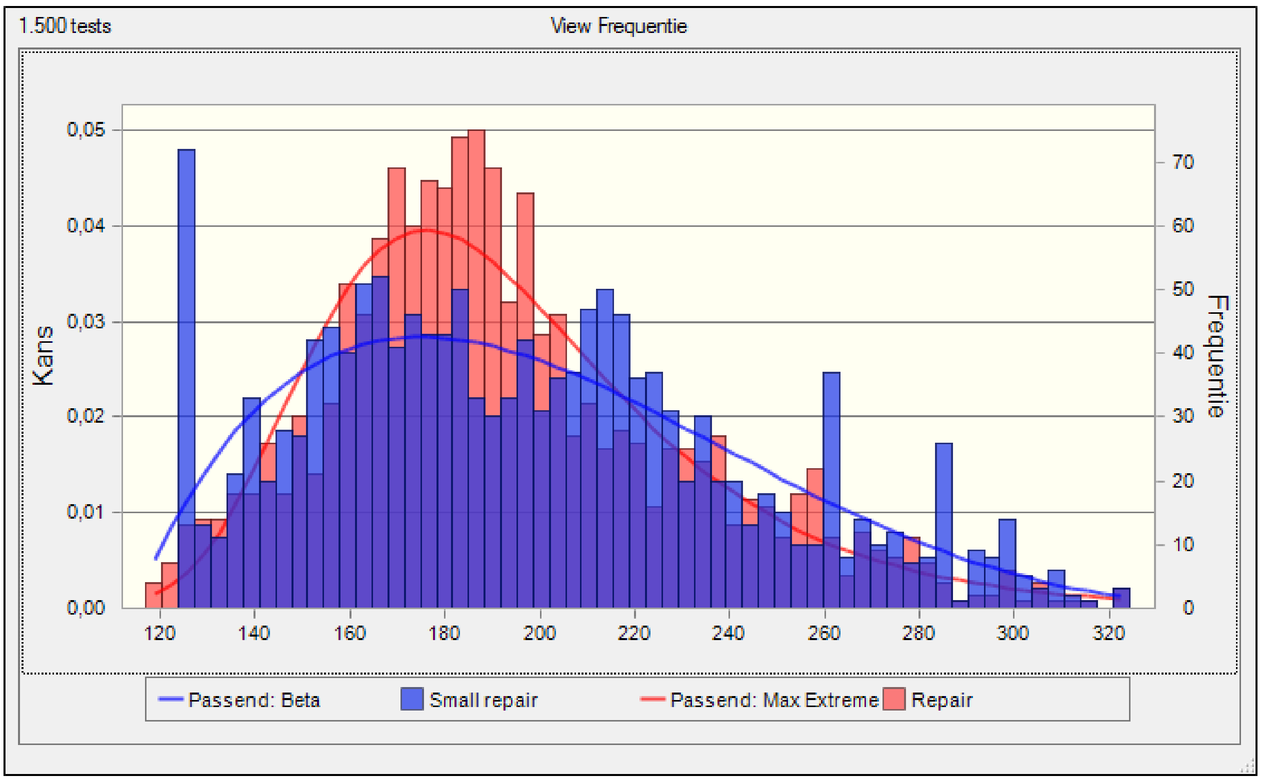


Figure 27: Frequency of the LCC, ‘small repair only’ scenario versus ‘all repair allowed’ scenario
NOTE - The found and displayed distribution for both LCC populations is the log-normal distribution

Figure 27 displays the results for this scenario’s LCC population, and compares it to the scenario without maximum amount for repairs. The differences are small, but this research finds a slightly higher annual LCC for the scenario with a maximum cost per repair (197 euro versus 193 euro in the scenario without maximum cost). We also noticed that the standard deviation of the found LCC population increased from 38 to 45. This is a consequence of the increased uncertainty on the service life of the appliance (which could be drastically ended if expensive repairs are not allowed). Surprisingly, the service life in both scenarios (15,04 for the ‘small repair only’ scenario, versus 16,51 for the ‘all repairs allowed’ scenario) does not considerably differ (18 months). This follows the lower likelihood of failures in the more expensive parts of the washing machine. So it might appear to be counterintuitive, but on average it is not a beneficial strategy to adhere a maximum cost per repair.

Warranty

A consumer is protected by a legally obliged warranty period of 2 years. Each defect within the first years following the purchase should be repaired at the expenses of the producers. It is possible to opt for a prolongation of the warranty period by three additional years, on the precondition that the consumer is willing to pay 90 euro for this prolongation. In the latter case, each defect within the first five years after the purchase of the appliance is repaired by the producer. All following repairs are at the expenses of the consumer. Figure 28 compares the situation in which a consumer decided not to prolong the warranty period to the initial 'repair' scenario. No maximum cost is assumed for repairs in both scenarios, but consumers do face variance in terms of the safety margin and the number of repairs allowed.

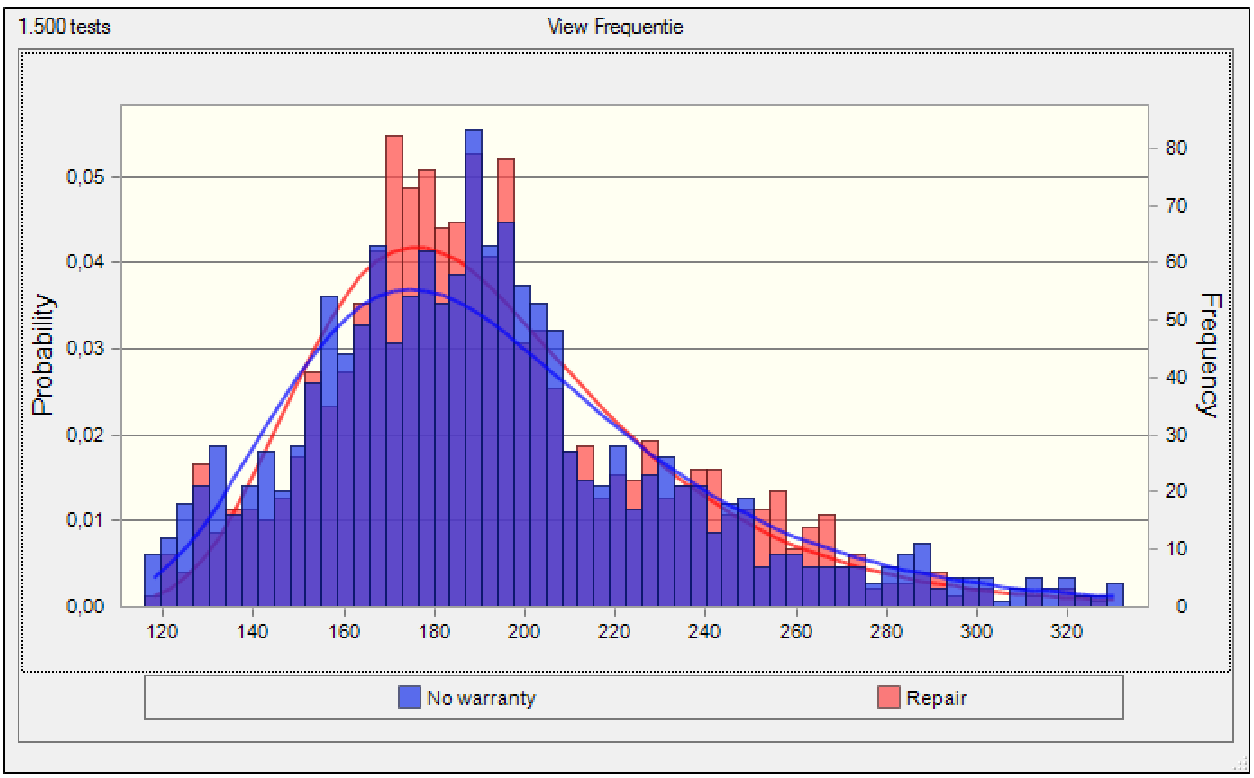


Figure 28: Frequency of the LCC, 'no warranty' scenario versus 'all repair allowed' scenario (including the option for the warranty) NOTE - The found and displayed distribution for the 'no warranty' scenario is the maximum extreme values distribution, a log-normal distribution is found for the 'all repair allowed' scenario.

On average, the annual LCC in both scenarios equals 193 euro. Hence, the additional cost of the warranty (90 euro) equals the NPV of the repairs a consumer can expect from the third to the fifth year of the washing machine's service life (the first two years are anyway covered by the legal warranty period). Our research does find a higher standard deviation in case a consumer does not opt for the warranty (increase from 38 to 46), indicating that this option is less interesting for risk-averse consumers. Hence, the additional warranty does not provide monetary gains, but does decrease the variance of the LCC (risk decrease) a bit.

- ***Replace***

Consumers are not obliged to repair malfunctioning washing machines. Instead they can opt for the disposal and replacement of the washing machine. In this case they do not face the costs of repair, but instead will have to account for the purchase price in case of a malfunction of the original machine. Note however that due to the discounting of future expenses, the NPV of the future purchase price will be lower than the actual purchase price. Following the rationale of discounting, the further in future the consumer needs to replace the washing machine, the lower the NPV of the replacement cost and the lower the contribution to the LCC of the ownership of a washing machine. In addition, this research does not take the entire purchase price into account if the service life of the replacing appliance exceeds the (prolonged) service life of the appliance in the repair scenario (see explanation above). This ensures that the repair and replace scenario's consider the same service life periods.

The results of the 1500 LCC calculations for the 'dispose and replace' scenario are compared to the similar calculations for the 'all repair allowed' scenario in Figure 29. From this figure it becomes apparent that the replace strategy results in a higher (average and annual) LCC for washing machines (217 euro instead of 193 euro). Over a period of 16,51 years the difference in annual LCC leads to a saving of 396,24 euro. Hence, the repair options are most beneficial in this context. In addition, the standard deviation increased from 38 to 50 in the 'dispose and replace' scenario. This makes the latter strategy less interesting for risk-averse consumers.

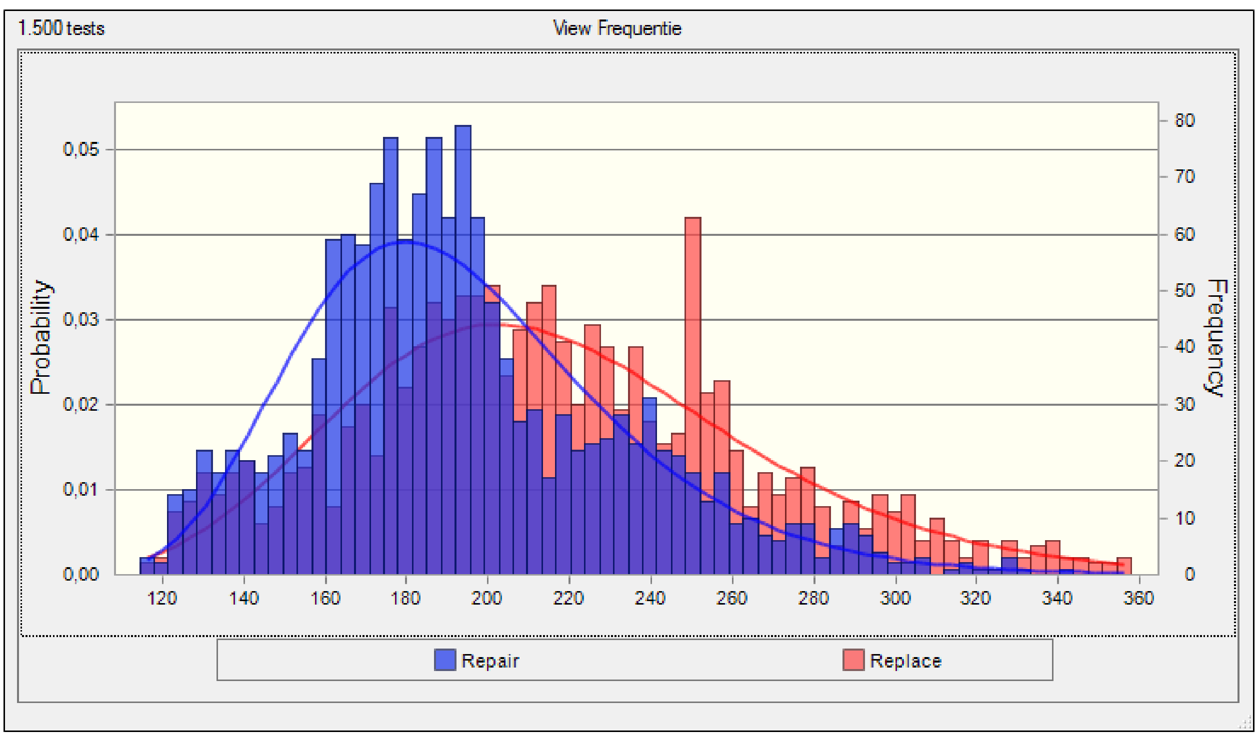


Figure 29: Frequency of the LCC, 'dispose and replace' scenario versus 'all repair allowed' scenario
NOTE - The found and displayed distribution for both scenarios is a log-normal distribution. Both scenarios assume that the consumer paid for 3 additional years of warranty.

- ***Overview***

Different scenarios have been run and compared to each other. Table 23 provides an overview of each scenario's main findings.

Table 23: overview of (annual) LCC, service life and standard deviation of the LCC per scenario

Scenario	Annual LCC (mean, euro)	St. Dev Annual LCC	Total LCC (mean, euro)	Service life (years)
Baseline (no repair, no replacement)	229	42	2470,91	10,79
Repair without maximum cost per repair	193	38	3186,43	16,51
Repair with maximum cost per repair	196	45	2947,84	15,04
Repair without warranty	193	46	3192,22	16,54
Replace without repair	217	50	3582,67	16,51

The overview demonstrates that continued reparation of washing machines is the most beneficial in terms of monetary gains from the consumer point of view. The annual LCC for the three repair scenarios is below the LCC for the baseline scenario and the replace scenario in which appliances are not repaired.

But also the results for the three repair scenarios differ. First, in monetary terms, it does not seem necessary to opt for additional warranty as this does not decrease the annual LCC. However, risk-averse consumers better opt for the warranty because it increases the certainty on the actual future LCC (less variance). Finally, opting for a maximum cost per repair has no gains whatsoever in comparison to the LCC in the scenario without the maximum cost (nor in terms of annual LCC, nor in terms of standard deviation). Table 23 demonstrates that this strategy manages to achieve the lowest variance, as well as the lowest annual LCC.

7.4 Results canister vacuum cleaner

- ***Life cycle cost - baseline***

The composition of the canister vacuum cleaner's LCC is presented in Figure 30. In comparison with the upright vacuum cleaner, the operational costs are less important for the canister vacuum cleaner (share of 16% versus 19% for filters, and a share of 8% versus 10% for energy). As a consequence, the costs related to the acquisition of the canister vacuum cleaner (purchase price, taxes, warranty) correspond to a more important aggregated share (76% versus 71%). The average service life for the canister vacuum cleaner is 8,84 years, which is comparable but slightly above the 8,34 years for the upright vacuum cleaner. Over the 8,84 years, the average total LCC found is 691 euro. Finally, an average annual LCC of 90 euro is found for the canister vacuum cleaner, which makes this type of vacuum cleaner a less expensive alternative compared to the upright vacuum cleaner. Note that the total LCC does not coincide with the average LCC multiplied with the average service life. This follows the observation that the found distributions for the service life and the average LCC differ. **Table** 24 provides an overview of the vacuum cleaner-specific costs and parameters used to calculate the LCC. Notice that this information is used for both the upright and canister vacuum cleaner.

Table 24: Overview of vacuum cleaner-specific costs and parameters, and accompanying sources

Type of cost	Cost	Source
Energy price	0,29 euro / kWh	EUROSTAT
Cost of delivery, installation and operational start-up	Not disclosed	/
Service and maintenance	Not disclosed	/
Parameter	**Value**	**Source**
Legal warranty	2 years, no cost	European Consumer Centre
Additional warranty	3 additional years, costs 40 euro	Retailer's website

NOTE – The reported energy prices vary considerably per quarter. Therefore, variation in the energy prices is introduced in the Monte Carlo analysis (each run has a unique energy price, above or below the average energy price reported in this table.

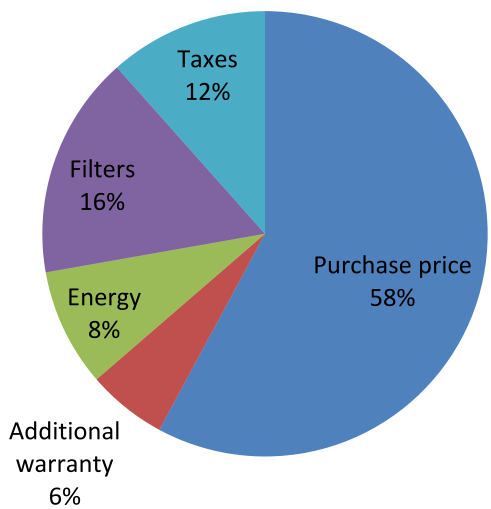


Figure 30: Composition of the LCC for the canister vacuum cleaner
NOTE - This LCC assumes that the consumer opts for an extension of the legal warranty period. Only the monetary costs are taken into account

- ***Repair***

In case repair is allowed, the service life of the canister vacuum cleaner can be extended, and the repair costs become part of the vacuum cleaner's LCC. The pattern in repair costs differs in comparison to the repair costs for the upright vacuum cleaner. First the repair costs are in general smaller. Second, the canister vacuum cleaner contains a higher number of parts which can break down.

The results of the new LCC calculation are presented in Figure 31. Due to the reparations of the vacuum cleaner, the service life of the appliance is extended from 8,84 to 13,44 years. As a consequence of the extended service life, the total LCC increased to 839 euro. However, the annual LCC decreased considerably to 69 euro while the LCC results are also less prone to variance. For these combined reasons, repair is a beneficial strategy for the canister vacuum cleaner. This corresponds to the findings for the upright vacuum cleaner and the washing machine.

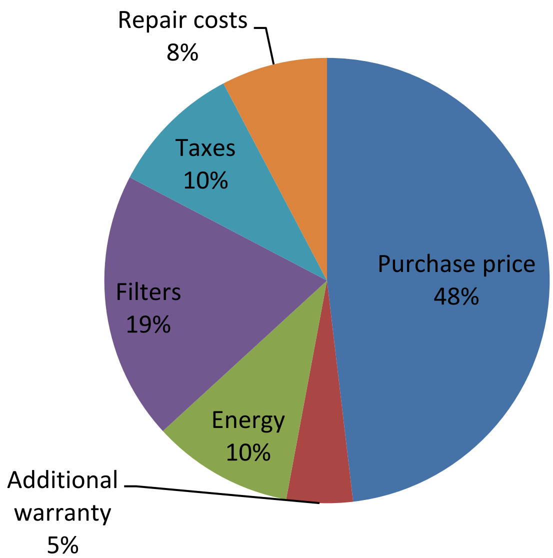


Figure 31: Composition of the LCC for the upright vacuum cleaner, in case of restricted repairs

Behavioural aspects

The reported annual LCC of 69 is an average for a log-normal distributed population of LCCs. Hence, the LCC results are prone to variance. The Monte Carlo analysis allows analysing each parameter's contribution to this variance (Figure 32).

All findings from this analysis correspond to the earlier findings for the washing machine and the upright vacuum cleaner. Only one result attracts attention: the relative low importance of the discount rate. This is explained by the relatively low costs in the years following the purchase, in relation to the costs at the moment of the purchase. For example, the cost of the most expensive repair in case of the upright vacuum cleaner represents 30,6% of its purchase price, while for the canister vacuum cleaner this is only 22,9%. Since the discount rate is used to calculate the NPV of those future (relatively low) costs, the discount rate also becomes a less important impacting factor for the LCC's variance.

In terms of the behavioural aspects, the number of repairs allowed and the safety margin are valid options to further decrease the annual LCC.

The number of repairs again is negatively correlated with the LCC. This is further examined in Figure 33. Note that the LCC only decreases when the number of allowed repairs increases to 2 or 3. A higher number of allowed repairs does not significantly impact the mean annual LCC anymore.

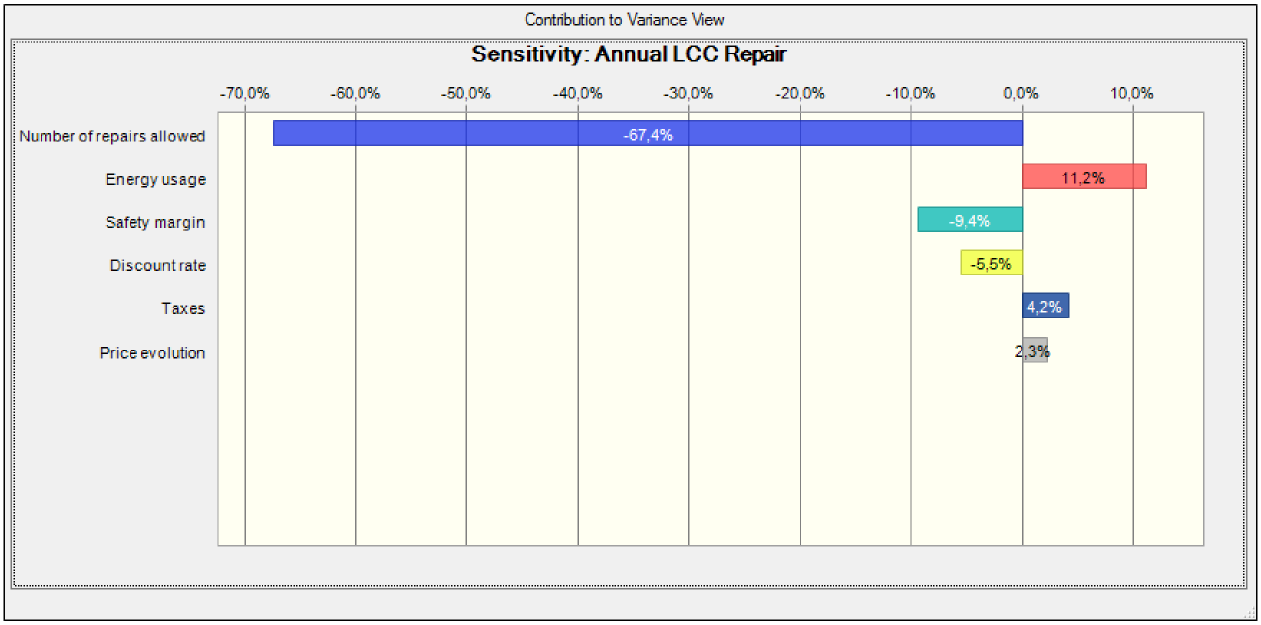


Figure 32: Contribution to variance in the LCC results (canister vacuum cleaner)

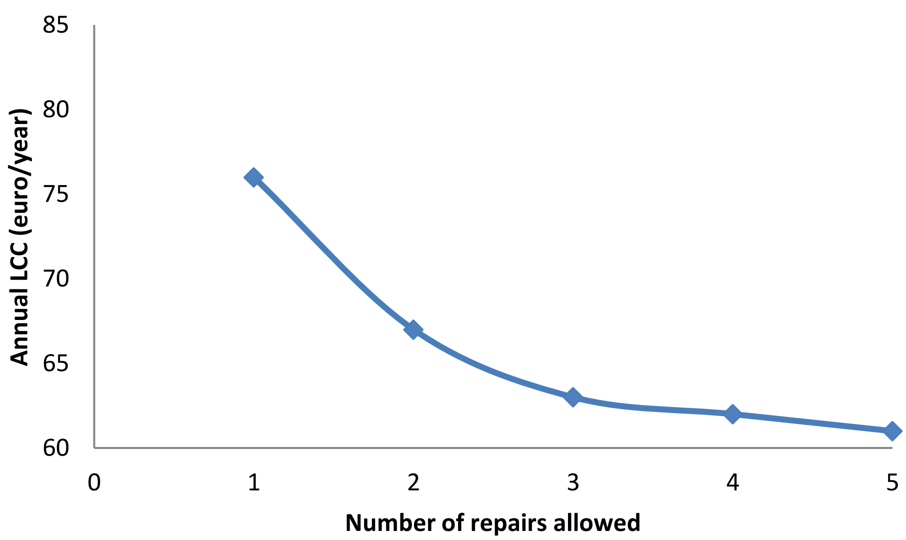


Figure 33: Mean annual LCC per predetermined number of repairs allowed
NOTE - each point in the scatter plot represents the mean of 1500 LCC calculations for each scenario of number of repairs allowed.

Small repair

In case a consumer sets a maximum value for repairs, this will impact the expected service life and LCC for the canister vacuum cleaner. The results of this scenario are presented in Figure 34. It can be observed that setting a maximum cost per repair is likely to increase the annual LCC (from 69 in the scenario without to 84 in the scenario with maximum cost per repair) and increase the variance (from 20 in the scenario without to 27 in the scenario with maximum cost per repair). To check more thoroughly whether the maximum cost indeed negatively impacts the expected annual LCC, this research also introduces variance in terms of the benchmark for maximum cost per repair. A normal distribution is specified with a maximum repair cost which allows all but three repairs, and standard deviation equivalent to 20% of the given mean to ensure wide variance. The given mean is set at 15% of the purchase price.

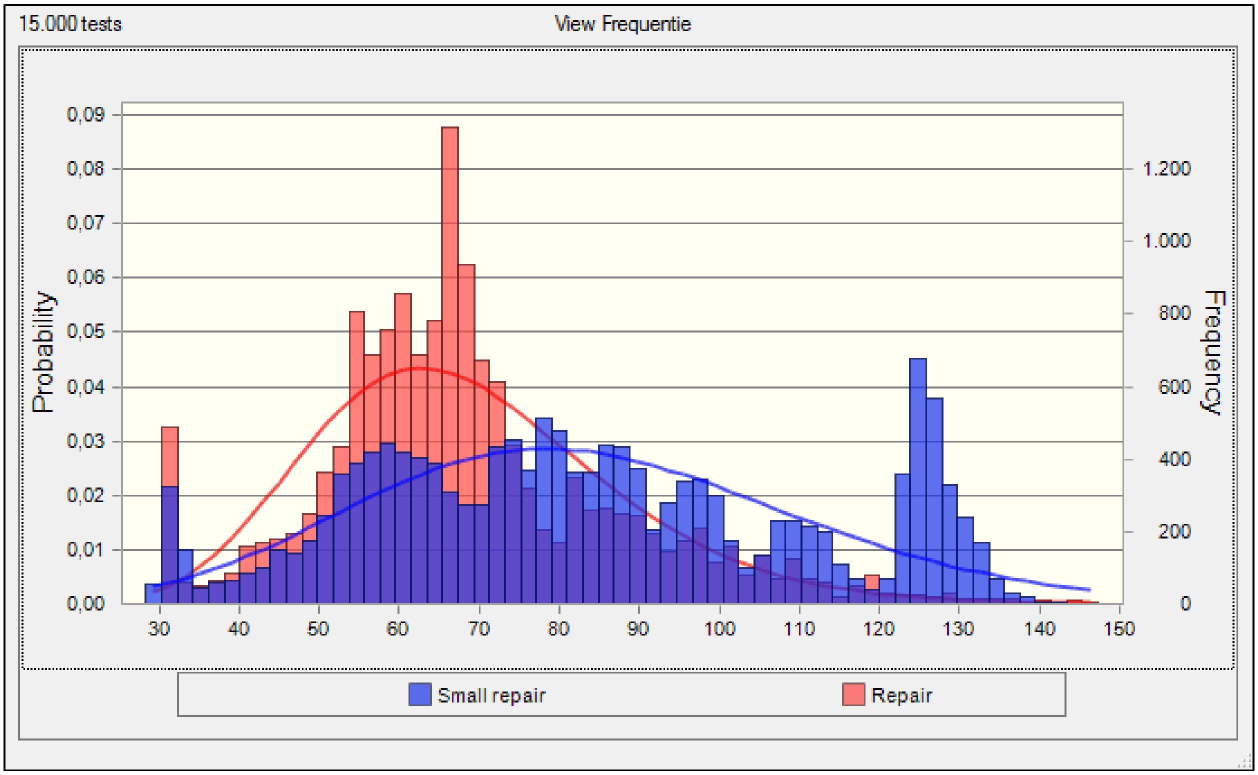


Figure 34: Frequency of the LCC, 'small repair only' scenario versus 'all repair allowed' scenario
NOTE - The found and displayed distribution for the LCC populations is the log-normal distribution for the repair scenario and the Gamma distribution for the small repair scenario.

Warranty

The cost of the additional warranty (40 euro for 3 years) on top of the legal warranty (first 2 years) proves beneficial for the canister vacuum cleaner. The explanation is twofold. First, the cost of the warranty is relatively low in comparison to the washing machine (falling below 10% compared to +15% for the washing machine) and again the proportion of the service life covered by the warranty is considerably longer.

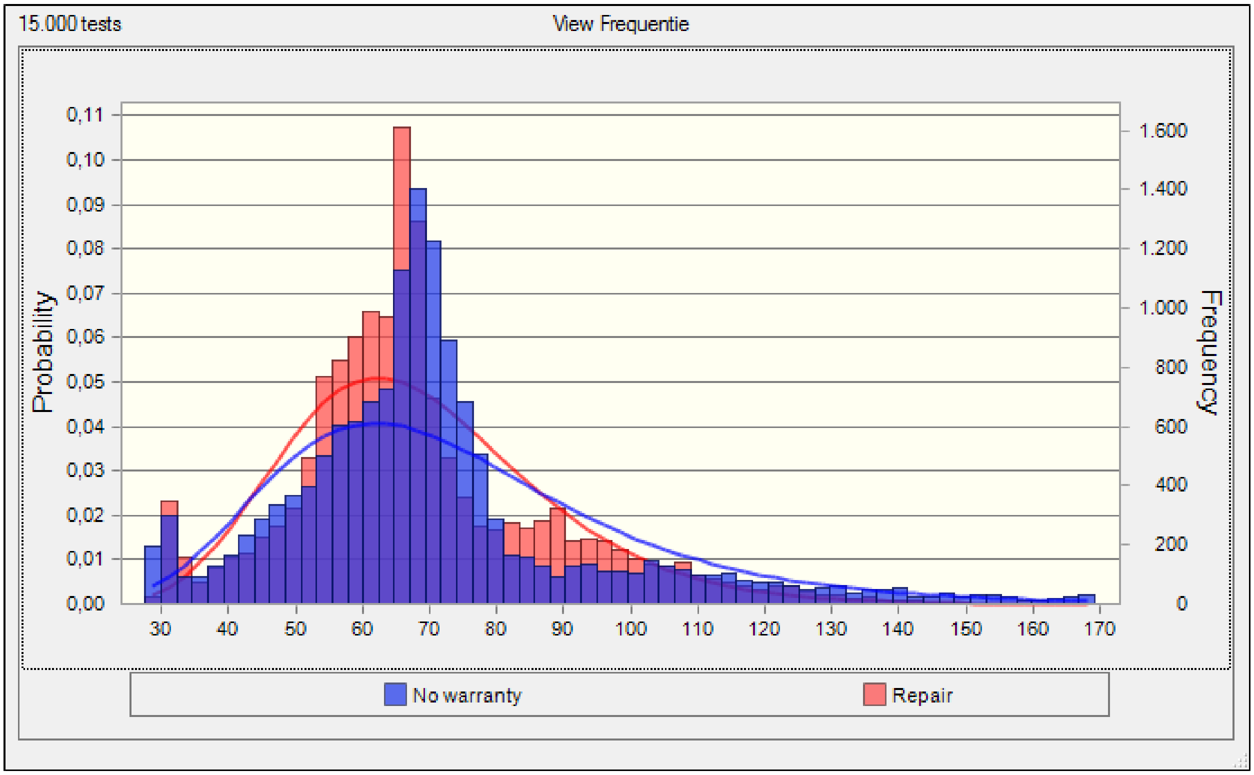


Figure 35: Frequency of the LCC, 'no warranty' scenario versus 'all repair allowed' scenario (including the option for the warranty) NOTE - The found and displayed distributions are the log-normal distribution for the repair scenario, and the maximum extreme values distribution for the scenario without warranty.

- ***Replace***

Just like in case of the washing machine, the replace scenario is not beneficial for the canister vacuum cleaner. Both the average annual LCC and the standard deviation for the annual LCC increased in comparison to the repair scenario (without maximum cost per repair, with warranty) (Figure 36). In addition, the expected annual LCC decreased in comparison to each repair scenario.

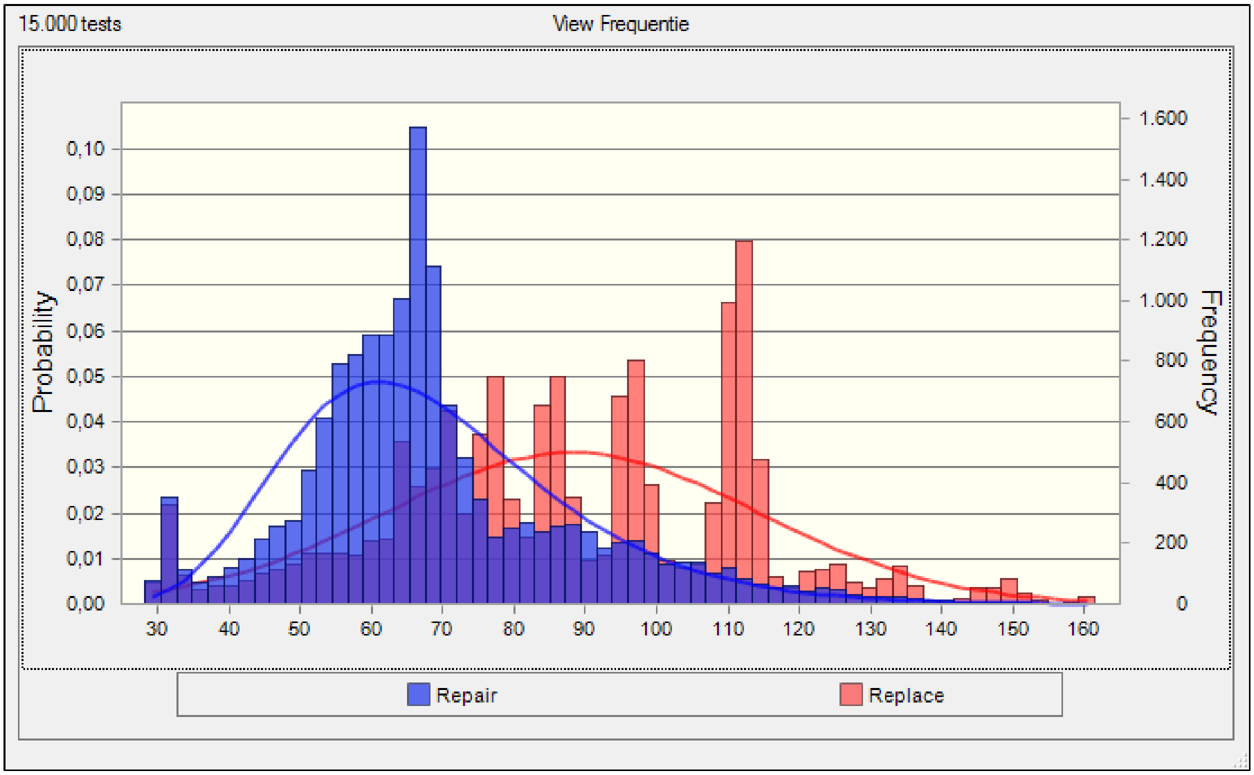


Figure 36: Frequency of the LCC, 'dispose and replace' scenario versus 'all repair allowed' scenario.
NOTE - The found and displayed distribution for the repair scenario is a log-normal distribution, and the gamma distribution for the replace scenario. Both scenarios assume that the consumer paid for 3 additional years of warranty.

- ***Overview***

All conclusions for the canister vacuum cleaner confirm and are in line with the conclusions for the upright vacuum cleaner. The repair strategy, adhering a safety margin and allowing a high number of repairs minimize the annual LCC of both types of vacuum cleaner.

Table 25: overview of (annual) LCC, service life and standard deviation of the LCC per scenario

Scenario	**Annual LCC (mean, euro)**	**St. Dev Annual LCC**	**Total LCC (mean, euro)**	**Service life (years)**
Baseline (no repair, no replacement)	90	25	691	8,84
Repair without maximum cost per repair	69	20	839	13,44
Repair with maximum cost per repair	84	27	738	10,40
Repair without warranty	75	34	778	12,11
Replace without repair	88	26	1063	13,44

7.5 Results upright vacuum cleaner

The analysis for LCC of the upright and canister vacuum cleaner occurs in accordance with the analysis for the washing machine. This chapter focusses on the results for the upright vacuum cleaner.

- ***Life cycle cost - baseline***

Figure 37 presents the composition of the LCC for an upright vacuum cleaner when the option of repair is not allowed, and the vacuum is not replaced. The overall mean LCC for the upright vacuum cleaner equals 614,20 euro, to be spend over an expected service life of 8,34 years. These 8,34 years equals the average service life for the 1500 simulation runs in the Monte Carlo analysis. This results in an average annual LCC of 74 euro.

Notice that for the upright vacuum cleaner, the share of the purchase price is more elevated in comparison to the washing machine's case. Together with the cost of the additional warranty and the taxes on the sales price, the costs related to the purchase of the vacuum cleaner (i.e. before the appliance becomes operational) account for 71% of the total LCC. The energy costs are much less important in comparison to the washing machine (10% versus 24%), while the regular renewal of the filters accounts for 19% of the total LCC.

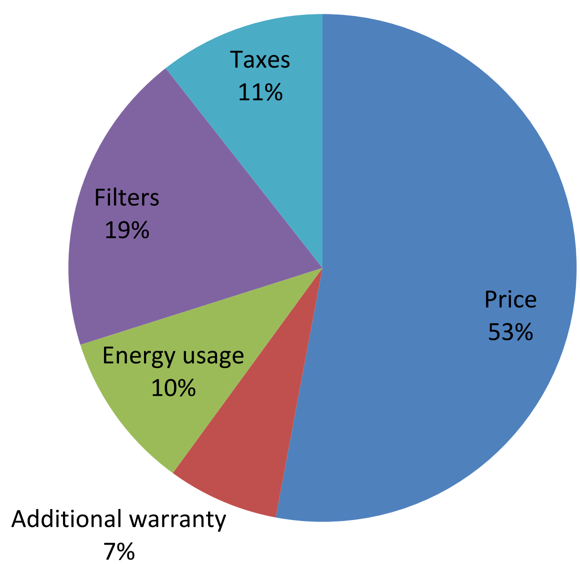


Figure 37: Composition of the LCC for the upright vacuum cleaner
NOTE - This LCC assumes that the consumer opts for an extension of the legal warranty period. Only the monetary costs are taken into account

- ***Repair***

Figure 38 presents the composition of the LCC in case of restricted repairs. In this rationale, 'restricted' implies that consumers adhere some kind of safety margin prior to the end of the expected service life in which they do not allow a repair anymore, and have a maximum number of repairs they accept within the service life of the appliance. Put differently, consumers will not repair an old device which approach the end of their expected service life. In comparison to the baseline scenario, the operational costs (energy and filters) became more important, while the costs associated with the purchase (purchase price, warranty, taxes) became less important. Note that the costs of repair account for a higher share of the LCC (10%) in comparison to the washing machine's LCC composition (5%).

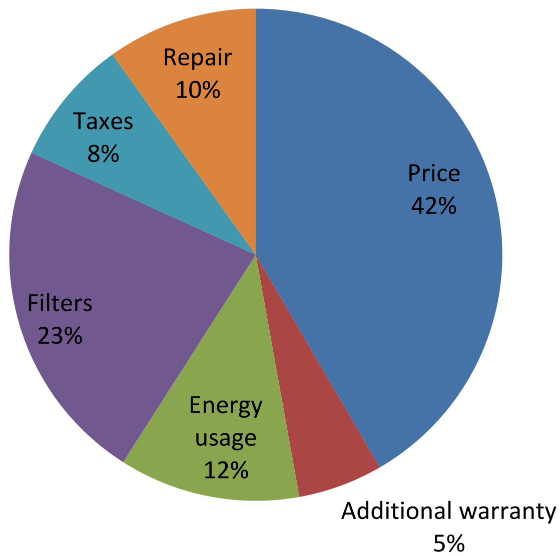


Figure 38: Composition of the LCC for the upright vacuum cleaner, in case of restricted repairs

Behavioural aspects

The contribution of each impacting factor to the variance in the LCC results for the upright vacuum cleaner is presented in Figure 39. The conclusions with respect to the discount rate, taxes, energy use and evolution of prices are in accordance with the conclusions for the same parameters in the case of the washing machine. Hence, the discount rate is negatively correlated to the LCC, and considerably (45,3%) explains the variance in the device's LCC. Price changes and energy use do not seem to considerably impact the LCC. Variance in taxes however is positively correlated to the LCC's variance.

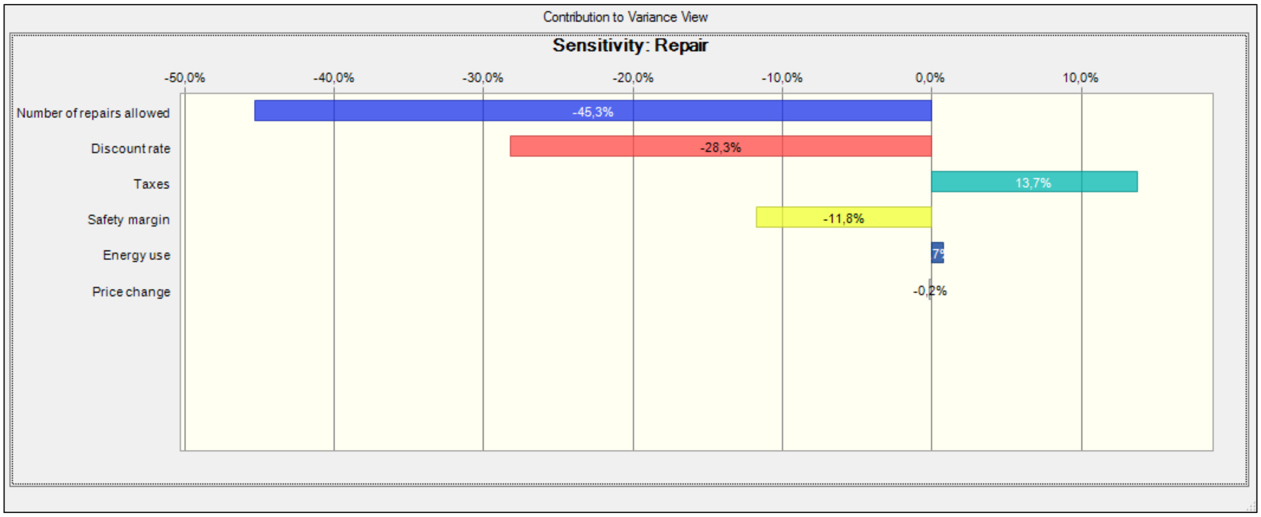


Figure 39: Contribution to variance in the LCC results (upright vacuum cleaner)

Also the conclusions with respect to the behavioural aspects are in accordance with the conclusions for the washing machine. However, in the case of the upright vacuum cleaner it should be stressed that the safety margin has a more important impact as it explains 11,8% of the variance in the annual LCC. Hence for vacuum cleaners the safety margin is a more effective strategy to decrease the LCC for the consumer. This is explained by the higher repair costs in relation to the purchase price (which is also observed in Figure 39). Also the number of repairs again is negatively correlated with the LCC. This is further examined in Figure 40. Note that the LCC only decreases when the number of allowed repairs increases to 2 or 3. A higher number of allowed repairs does not significantly impact the mean annual LCC anymore.

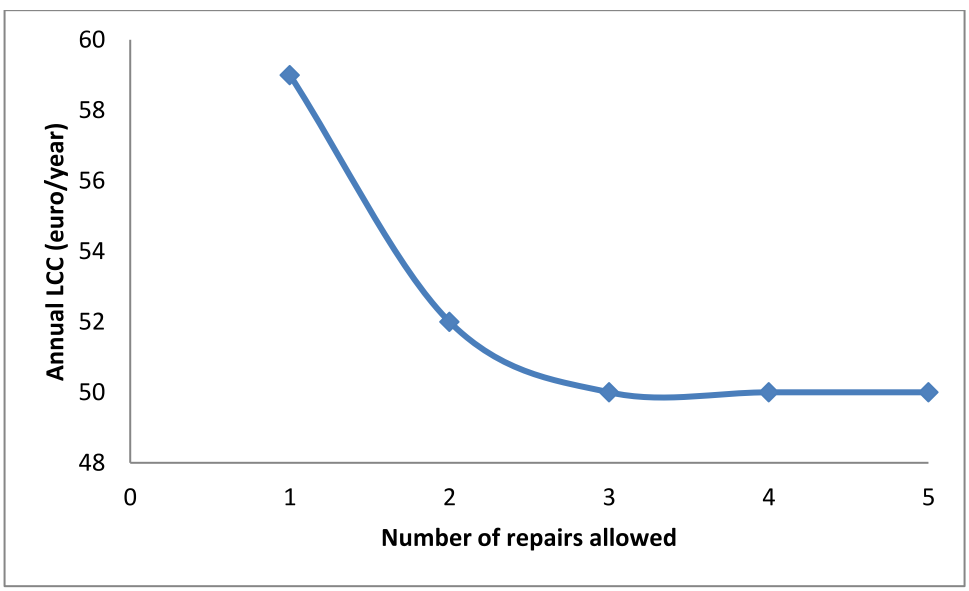


Figure 40: Mean annual LCC per predetermined number of repairs allowed
NOTE - each point in the scatter plot represents the mean of 1500 LCC calculations for each scenario of number of repairs allowed

Small repair

In accordance with the washing machine, it does not prove beneficial to apply a maximum cost per repair. This is demonstrated in Figure 41, which compares the LCC results for the repair scenario (without maximum cost) and the small repair scenario. Both the variance and the average LCC increase once the strategy with a maximum cost per repair is adhered. The presence of the spikes in the LCC frequency visualisation is explained by the limited number of defect types (5), and the assumption that a defect leads to replacement of the appliance

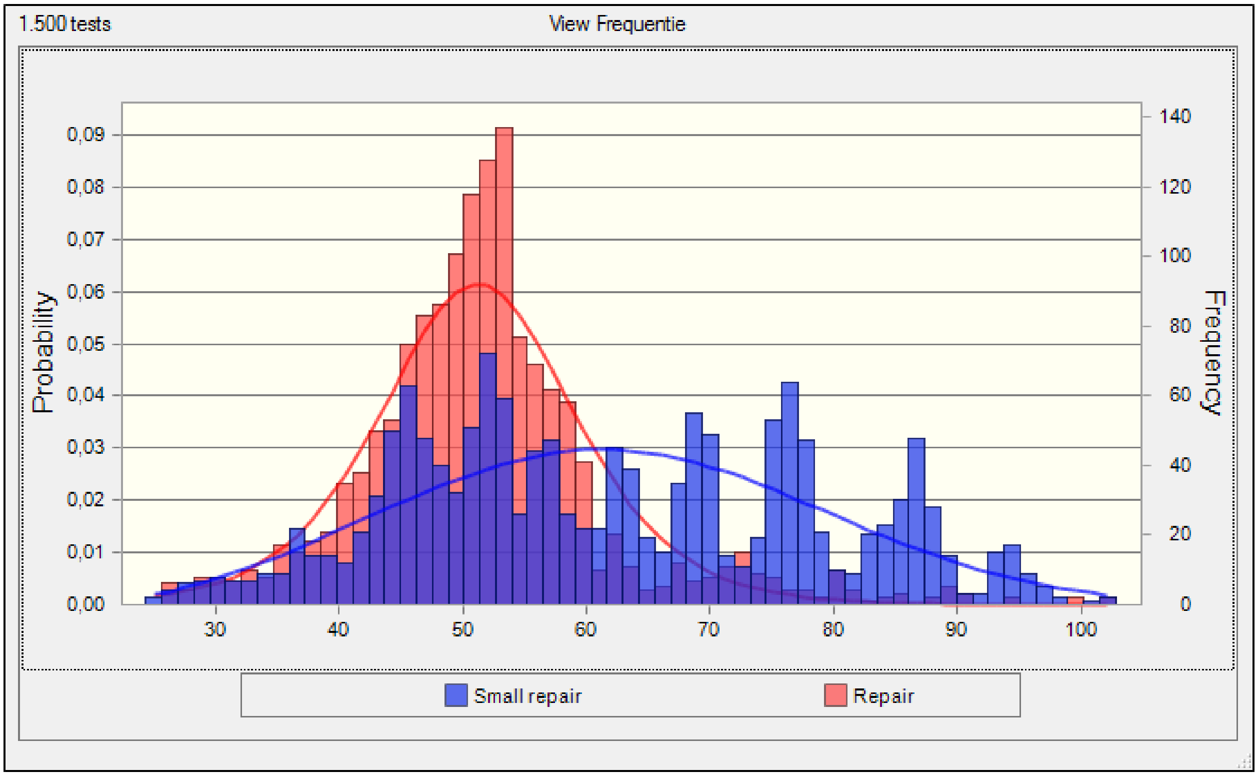


Figure 41: Frequency of the LCC, 'small repair only' scenario versus 'all repair allowed' scenario
NOTE - The found and displayed distribution for the LCC populations is the log-normal distribution for the repair scenario and the Weibull distribution for the small repair scenario.

Warranty

In contrast to the washing machine, the warranty has a distinct positive impact on the annual LCC of the upright vacuum cleaner. The annual LCC increased from 53 euro in the scenario with the additional warranty to 58 euro in the scenario without the additional warranty (hence, with the sole protection by the legal two-year warranty). This implies that the cost of the warranty is sufficiently compensated by potential savings following avoided repair costs. The explanation for this conclusion is twofold. First, the cost of the warranty (40 euro) is less than 15% of the purchase price. In case of the washing machine this was above 15%, making the warranty for the vacuum cleaner relatively cheaper. Second, the prolongation of the two-year legal warranty period by an additional three years creates a total warranty period which covers a larger proportion of the expected service life. Since a larger part of the service life is covered, the warranty becomes more interesting.

On the other hand, the variance decreased in the scenario without warranty (from 12 to 10). This is likely due to the increased service life in the repair' scenario (with additional warranty) in comparison to the scenario which only considers the legally obliged warranty. Hence risk-averse consumers who seek more control on the future LCC can opt for the legal warranty only if they are willing to except the higher LCC in return for more certainty on their future expenses. Notice that the additional warranty in the repair scenario also manages to achieve a longer service life (13,52 years) compared to the scenario without the additional warranty (12,71 years).

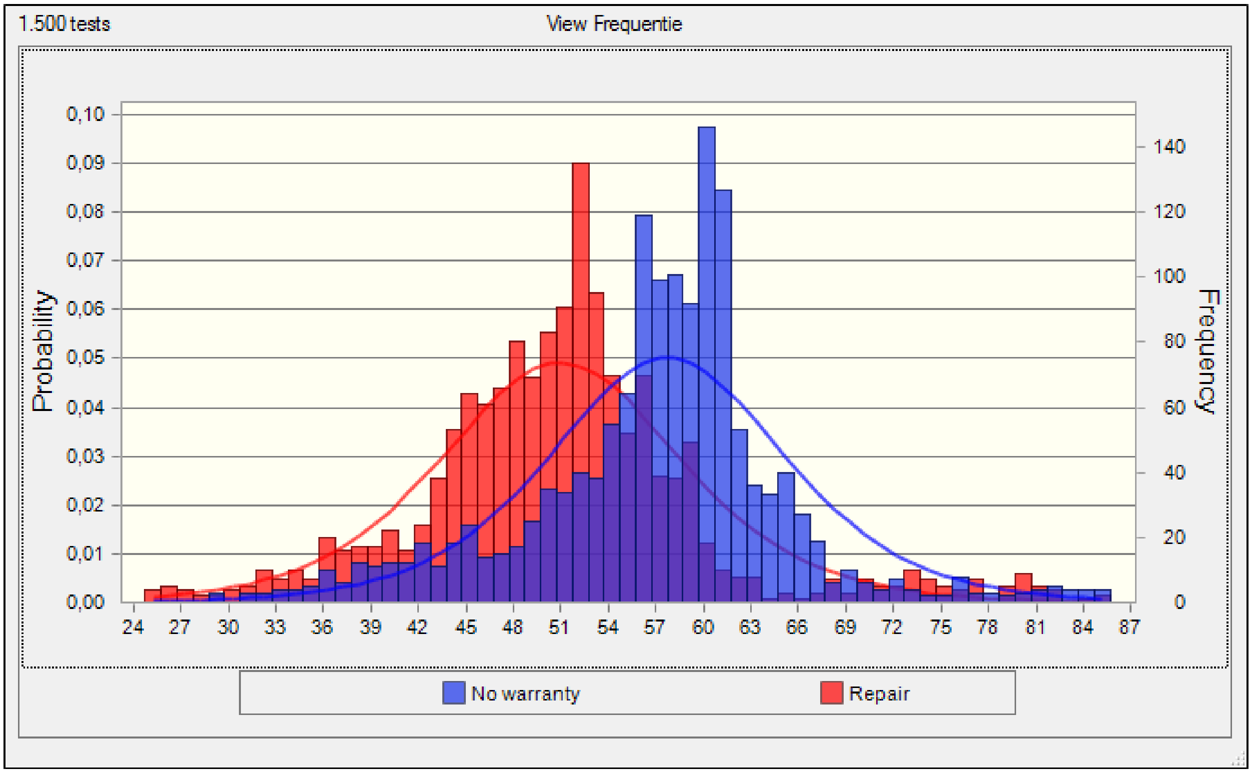


Figure 42: Frequency of the LCC, 'no additional warranty' scenario versus 'all repair allowed' scenario (including the option for the additional warranty)
NOTE - The found and displayed distributions for both scenarios are the log-normal distribution.

- ***Replace***

Finally, we compare the replace scenario to the repair scenario over the average service life of the repair scenario. Note that this research only takes the proportion of the purchase cost for the replacing vacuum cleaner into account which corresponds to the share of the service life of the vacuum cleaner which coincides with the assessed period. In this rationale, the purchase cost includes the purchase price, taxes to be paid at acquisition and – if applicable – the cost of an additional warranty. Nevertheless, this research finds a higher average annual LCC for the replace scenario, suggesting that the repair strategy is more interesting in economic/monetary terms. The presence of the spikes in the LCC frequency visualisation is explained by the limited number of defect types (5), and the assumption that a defect leads to replacement of the appliance.

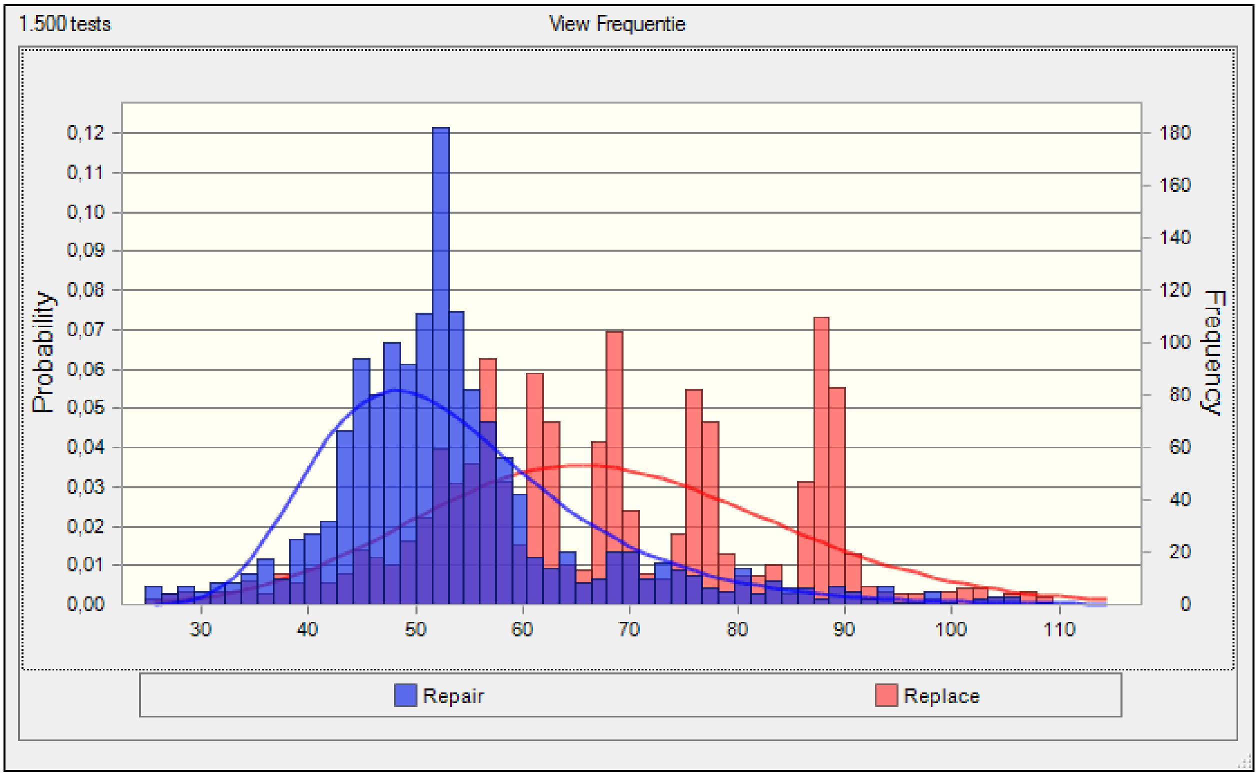


Figure 43: Frequency of the LCC, 'dispose and replace' scenario versus 'all repair allowed' scenario
NOTE - The found and displayed distribution for the repair scenario is a log-normal distribution, and the gamma distribution for the replace scenario. Both scenarios assume that the consumer paid for 3 additional years of warranty.

- ***Overview***

The conclusions for the upright vacuum cleaner correspond to the assumptions for the washing machine. I.e. each repair strategy further optimises the average annual LCC in comparison to the baseline or replace scenario. However, not each repair scenario is as efficient as the others. In contrast to the washing machines, it is found that the warranty does positively impact the average annual LCC for the upright vacuum cleaner. This can be explained by the relatively high repair costs in relation to the upright vacuum cleaner's purchase price. In addition, the additional warranty period equals the additional warranty period of the washing machine, but the expected service life of a washing machine considerably surpasses the expected service life of a vacuum cleaner. Hence, the vacuum cleaner's extended warranty period encompasses a bigger share of the appliance's total service life. On the downside, the warranty does increase the variability in the average annual LCC results from 10 to 12. Finally, also in the case of vacuum cleaners it is found useless to adhere a maximum cost per repair.

Table 26: overview of (annual) LCC, service life and standard deviation of the LCC per scenario

Scenario	Annual LCC (mean, euro)	St. Dev Annual LCC	Total LCC (mean, euro)	Service life (years)
Baseline (no repair, no replacement)	74	17	614,20	8,34
Repair without maximum cost per repair	53	12	720,27	13,52
Repair with maximum cost per repair	62	16	691,92	11,16
Repair without warranty	58	10	737,18	12,71
Replace without repair	68	17	919,36	13,52

Chapter 8: Conclusions

8.1 Developed repairability assessment method

The developed method is a semi-quantitative method. A general framework has been developed that provides a clear and meaningful structure for each repairability criteria according to the criteria type and the related repair step. The defined repairability criteria are in line with current ongoing initiatives at European level.

The developed methodology provides a complete set of criteria related to the different aspects of repairability through the whole repair cycle. Provided information, product design and offered service from the manufacturer during the use phase are taken into account.

In total 24 criteria are proposed and each of them receive a score depending on the selected option. The different options for each criterium are described in detail and, where possible, measurable data is used. Criteria have been defined related to information provision, such as explanation of error codes, disassembly instructions or spare parts references. Other criteria assess the product design for repair, such as ease of disassembly or individual replacement of priority parts. One of the criteria, related to ease of disassembly, is based on the quantitative eDIM evaluation. Finally, there are also criteria that assess the offered repair services of the manufacturer during the use phase of the product. Although the developed criteria focus on the technical feasibility of repair, for some criteria, such as access to spare parts and repair services, the related cost has been taken into account.

Overall the weights for the generic assessment tool are quite evenly distributed, with some more emphasis on product design (38% of total score), compared to information provision (29%) and service provided by the manufacturer during the use phase (34%). Depending on the product type, the weights of the criteria can be adapted.

Some criteria related to the repairability assessment can be dependent of the targeted priority parts. Before the start of the repairability assessment a list of priority parts should be compiled, if not already available for the relevant product group. Priority parts are independent of current difficulties to be replaced or repaired, hence the priority parts should be identified taking the following into account:

- Most frequent failure modes or misuses of products
- Parts that are most likely to be replaced or repaired during the lifetime of a given product group
- Functional criticality

The developed methodology provides a complete set of criteria related to the different aspects of repairability through the whole repair cycle. However, a number of parameters has to be defined at product group level such as:

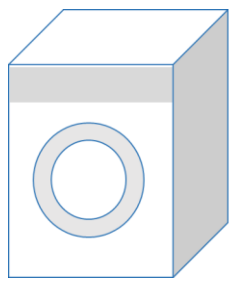
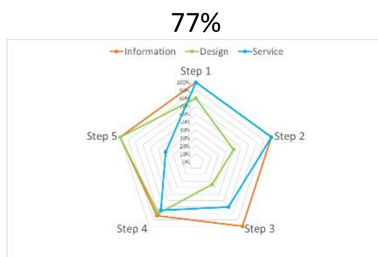
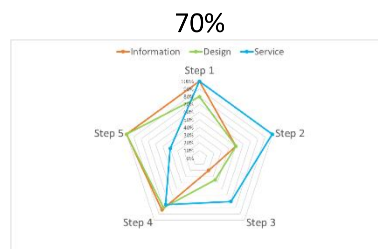
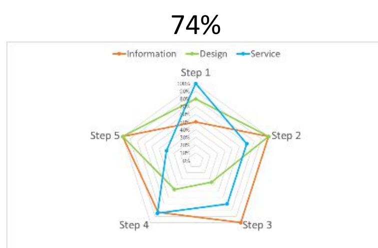
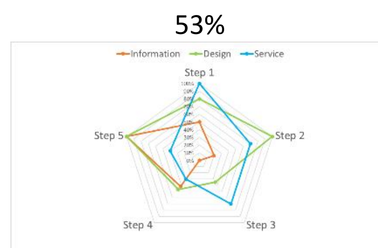
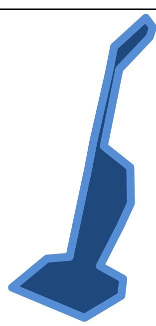
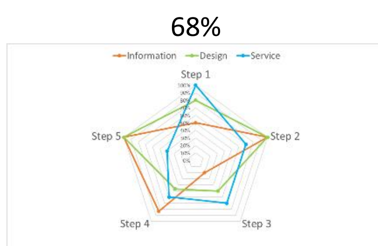
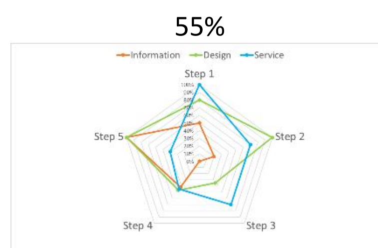
- Reference value for the disassembly metric (eDIM)
- List of priority part and common failure modes
- Level of detail of provided information

- Length of the required service (depending on average expected product lifetime)
- Relative cost and availability of spare parts
- Size of labels

Many synergies and similarities exist between maintenance, repair and upgrading. According to the authors, there is no added value of making a clear distinction between these activities and the repairability assessment method could be used for assessing ease of maintenance and upgrading of ErPs. The list of priority parts should be adapted accordingly.

8.2 Repairability method applied to case studies

The main results of the case studies are summarized below.

Product model	Repairability score for professional repairers	Repairability score for consumers
		
		
		

In all cases the repairability score for a professional repairer is higher than for a consumer, partly because of the limited information that is available for consumers. For the vacuum cleaners, the accessibility of spare parts is also better for professional repairers compared to consumers.

The main conclusion or recommendation to improve repairability for each case study is detailed below.

Based on the repairability assessment the conclusions for the assessed washing machine are summarized as follows:

- There is limited difference between repairability scores for consumers or authorized repairer.
- For increased ease of specific product model identification, the product model reference number should be included on the product in a durable manner. Currently the product model reference number is included on removable labels.
- Overall the information for the washing machine contains most of the relevant items related to repair. A minor improvement could be to allow for 3D printing for a number of simple parts such as switches. Furthermore the information score for consumers is significantly lower because less information is made available to them.
- For improved failure detection, the failure indication could be more visually intuitive rather than a coded interface.
- The ease of disassembly could be improved if the eDIM of partial disassembly related to the washing unit, drain pump and outlet hoses would be reduced for example by limited the number of required steps to access those parts.
- The ease of disassembly could be further improved by limiting the number of tools that are required to 'standard' tool.
- Overall all spare parts are made available to consumers within a reasonable price range considering the initial purchase price of the WM. However the repairability score could be further improved if spare part become less expensive.

Based on the repairability assessment the conclusions for the assessed canister vacuum cleaner are summarized as follows:

- For increased ease of specific product model identification:
    - the EAN code (barcode) should be present on the product itself and not on the packaging. Generally, it is assumed that packaging is not kept during the whole product lifetime.
    - the product model reference number should be included on the product in a durable manner. Currently the product model reference number is included on removable labels.
- Overall the information for the canister VC contains most of the relevant items related to repair. A minor improvement could be to allow for 3D printing for a number of simple parts such as switches or product casing. Furthermore the information score for consumers is significantly lower because less information is made available to them.
- The product design could be improved for repairability by increasing the number of spare parts made available or limiting the number of key components that need to be jointly replaced in case of failure (e.g. hose that included electronic component)
- The ease of disassembly can be improved by reducing the eDIM of partial disassembly for the motor and wheels and by ensuring access to connections to be released with a standard tool.
- In case of failure, consumers are referred to third party repair service. Although some information on troubleshooting is available to consumers, no additional technical support is foreseen in case

of self-repair. If consumers seek support from third party authorized repairers, even if the repair is not finalized, a fee will apply for failure diagnostic. To improve the overall repairability of the VC, increased technical support for self-repair to consumer could be considered.
- Repairability score could also be improved by ensuring accessibility to all spare parts for consumers.

Based on the repairability assessment the conclusions for the assessed upright vacuum cleaner are summarized as follows:

- For increased ease of specific product model identification:
  - the EAN code (barcode) should be present on the product itself and not on the packaging. Generally, it is assumed that packaging is not kept during the whole product lifetime.
  - the product model reference number should be included on the product in a durable manner. Currently the product model reference number is included on removable labels.
- Overall the information for the canister VC contains most relevant items related to repair. Although no detailed disassembly instruction is included in the service manual, the design seems to be sufficiently intuitive for disassembly as no major issue where encountered during the disassembly tests for this study. A minor improvement could be to allow for 3D printing for a number of simple parts such as switches or product casing. Furthermore the information score for the consumer is significantly lower because less information is made available to them.
- The ease of disassembly can be improved by reducing the eDIM of partial disassembly for the motor, wheels and battery.
- Some key components have to be jointly replaced in case of failure. In order to increase repairability, this should be avoided.
- Similar to canister VCs, to improve the overall repairability increased technical support for self-repair to consumer could be considered.
- Repairability score could also be improved by ensuring accessibility to all spare parts for consumers.

8.3 Lifecycle costing from a consumer perspective

- ***Repair versus dispose & replace***

This research finds that all of the analysed repair scenarios managed to decrease the average annual LCC for the washing machine, and both types of vacuum cleaners. In addition, in most cases the repair strategy also managed to decrease the variance in the average annual LCC. This research especially focusses on the annual LCC in order to compare scenarios with different service lives. The repair scenario is not only beneficial in economic terms (lower annual LCC), the strategy also manages to significantly extend the service life of the appliances. The benefits of making longer use of the materials are out of scope of this research however.

- ***Repair options***

Once a consumer opts for repair, it is still required to decide upon a number of parameters. The behavioural aspects taken into account in this research are:

- Safety margin: does the consumer allow a repair at a moment close to the end of the expected service life of the appliance?
- Number of repairs allowed: a consumer might lose faith in an appliance after a number of (repaired) defects and decide to replace the appliance anyway.
- Maximum cost per repair: if the repair cost is relatively high in comparison to the purchase price, the consumer might not find it worth to repair the appliance.

Those behavioural aspects are found influential for an appliance's LCC, which is also in line with Bobba, Ardente and Mathieux [8] who stressed the importance of the individual's behaviour in LCC and repairability of an appliance.

More in particular, this research finds that applying a safety margin decreases the expected annual LCC. While it might appear counterintuitive, it is best to allow a high number of repairs once you opted for the repair strategy. This enables the appliance to acquire a return (in terms of savings through a decreased annual LCC) on the first investments in the reparations. Finally, applying a maximum cost per repair (and hence discarding expensive reparations) does not manage to decrease the annual LCC significantly. Especially in case of both types of vacuum cleaners this strategy even increased the annual LCC. In case of the washing machine, the increase in annual LCC due to the maximum repair costs was rather small. But in the latter case the variance in the LCC results increased, creating higher risk for the consumer.

The optimal safety margin, number of allowed repairs, and maximum cost per repair can only be determined by applying linear programming, minimizing the annual LCC. But this type of analysis is out of scope of this research.

- ***Warranty***

On the one hand, the warranty is found beneficial for both types of vacuum cleaners. On the other hand, the warranty did not impact the annual LCC for the washing machine but did increase the variance of the LCC results. This made the warranty a less interesting option in case of the washing machine. This analysis finds that the warranty becomes interesting following the combination of two elements. At first, the price of the additional warranty should be sufficiently low in order to compensate for the savings due to avoided repair costs. Second, the extension of the warranty should span a sufficiently large period of the entire expected service life of the appliance.

Also for this conclusion, we stress that the optimal cost per additional year of warranty can be determined following a linear programming exercise, but this type of research is out of scope of this research.

8.4 Next steps

Some challenges have been identified when applying the developed method. These challenges need to be further explored to refine and improve the current proposed repairability criteria.

An important challenges is the identification of priority parts and failure modes. Because all components can fail, a cut off rule needs to be defined. There are different possibilities. The cut-off can be defined as minimum number of parts (e.g. top 5 most likely to fail components) or it could be set to cover a minimum percentage of likely failures (e.g. 75% of failures). Furthermore, within a specific product group an identified priority part may not be relevant to all product models, such as carbon brushes for washing machines. As products are continuously developed, the number and type of priority parts may change over time.

Furthermore, the availability of spare parts from third parties is not straightfoward to take into account. First, manufacturers are not responsible and cannot control further distribution downstream of (original) spare parts. Second, the compatibility and quality of the spare parts are difficult to verify. Another difficulty is to deal with priority parts that are covered by an extended warranty. In the current study these were not treated differently because even if a part is covered by such an extended warranty, typically the replacement will not be completely free of charge.

Another challenge that was faced during the case studies is the distinction between maintenance, repair and upgrade. At the start of the project, the aim was to clearly separate between these different actions as maintenance aims to avoid repair and because upgrading provides a product with a slightly different function or capacity. In practice however maintenance instruction provided to users may also serve for repair (e.g. cleaning of a filter). Also in consumer surveys, filters were often regarded as failure requiring repair while this is considered to be part of regular maintenance by manufacturers.

In general, devices are becoming increasingly complex as they include more electronic components. The fact that there more (electronic) components are integrated in a product increases the likelihood of a failure occurring during the lifetime of the product. In order to achieve increased material efficiency through extended product lifetime with repair, it will not be sufficient to expect more repairable products from manufacturers, also consumers should be aware that less complex products will typically be more robust. The consumer should only choose products with specific features if this is relevant for his intended use.

Additionally, the different stakeholders should work together to define which type of products and which type of failure can be repaired by consumers through self-repair. A number of (simple) failures can be adequately handled by a consumer without any safety issue or unsafe use arising. However, in some cases professional repair is required. In those cases the aim should be to improve the provided service to consumer: increase accessibility, reduce cost and provide temporary product replacement during repair.

A policy tool that could be used is to extend the warranty period. The warranty period could be defined per product group depending on the average expected product lifetime. The lifecycle costing carried out in this study has indeed concluded that an extended warranty is beneficial if a sufficient part of the expected lifetime is covered by the warranty. Additionally, it was observed that companies manage to reduce the number of returned or failed products during the warranty period below 3%. It is expected that a similar target would be applied to the extended warranty period. However, further research should be carried out to investigate the full consequence of such an extended warranty. Even if the extended warranty is free of charge, it is most likely that this could increase the purchase price. Furthermore, in case of low grade products produced at lower cost, companies may more often decide to replace the failed products rather than repair it, which would not contribute to the overall goal of extended product lifetime to increase material efficiency.

Further research is needed to confirm the correlation between the single score obtained with the proposed repairability method and the ease of repair in real life. In the meanwhile, a number of specific items could be selected to better inform consumers. For example the possibility to replace or upgrade priority parts, the ease of disassembly expressed in time with the eDIM metric or the maintenance and repair service offered during the use of the product. In addition, the lifecycle costing demonstrated the importance of a voluntaristic strategy in the context of repair decisions by the consumer. The lifecycle cost per annum decreases considerably when the consumers allows a high number of repairs of a single device. This observation even holds in case the repair involves a high cost. Only in case the device approaches the end of its expected lifetime, the consumer should become reluctant towards the repair of malfunctioning devices.

The broader use of the developed repairability criteria should be further investigated by applying the method to a larger number of products. Another step toward the implementation of the tool would be to ensure the consistent use of the tool and the robustness of the obtained results (replicability of the method). For example, a test panel of a selected stakeholder could apply the developed method in a pilot project. Such a pilot project involving different stakeholders along the supply chain could also be used to develop vertical criteria for specific product groups.

Other steps that could be investigated at a Benelux-level as laboratory within Europe are the ease of access for the consumer to reparability services (and other types of information for the consumer like labeling) and the development of business models to demonstrate that reparability can be an opportunity for companies

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