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Final report

Methods and standards for assessing the repairability of electrical and electronic devices

Strengthening material efficiency under the Ecodesign Directive

by:

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Abstract: Methods and standards for assessing the repairability of electrical and electronic devices

The repair of energy-related products is associated with numerous ecological, social, and economic benefits, yet defective products hardly ever get repaired in practice to date. The project therefore aims to strengthen the material efficiency of energy-related products, focusing on the repairability of electrical and electronic devices. Firstly, we develop a conceptual framework for assessing the repairability. Based on this, we secondly identify indicators that influence repairability, based on existing approaches. Subsequently, we test the applicability of those that were assessed as key indicators through practical case studies for several tumble dryers and printers. Based on the empirical findings, we develop an assessment system for the repairability of energy-related products. Finally, we recommend measures that can be integrated into the existing policy framework to strengthen the repairability and therefore the material efficiency of energy-related products.

Kurzbeschreibung: Methoden und Normen zur Bewertung der Reparierbarkeit von Elektro- und Elektronikgeräten

Die Reparatur von energieverbrauchsrelevanten Produkten ist mit zahlreichen ökologischen, sozialen und ökonomischen Vorteilen verbunden, dennoch werden defekte Produkte in der Praxis bisher kaum repariert. Das Vorhaben zielt daher darauf ab, die Materialeffizienz von energieverbrauchsrelevanten Produkten zu stärken, wobei die Reparierbarkeit von defekten elektrischen und elektronischen Geräten im Fokus steht. In diesem Sinne wird zunächst ein konzeptioneller Rahmen zur Bewertung der Reparierbarkeit entwickelt. Darauf aufbauend werden, basierend auf bestehenden Ansätzen, Indikatoren identifiziert, welche die Reparierbarkeit beeinflussen. Anschließend wird die Anwendbarkeit der als zentral bewerteten Indikatoren beispielhaft anhand praktischer Fallstudien für mehrere Wäschetrockner und Drucker überprüft. Basierend auf den empirischen Erkenntnissen wird ein Bewertungssystem zur Reparierbarkeit von energieverbrauchsrelevanten Produkten entwickelt. Abschließend werden Empfehlungen formuliert, die in produktpolitische Instrumente intergiert werden können, um die Reparierbarkeit und damit die Materialeffizienz von energieverbrauchsrelevanten Produkten zu stärken.

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List of abbreviations

WS	Working step
AVP	German Waste Avoidance Program (Abfallvermeidungsprogramm)
DMPF	Drive motor for paper feed
approx.	Approximately
DBBW	Drive belt blower wheel
Benelux	Belgium, Netherlands, Luxemburg
AB	Assembly
CP	Components
e. g.	For example
EoL	End-of-Life
FRSSF	Feeder roller stack sheet feeder
etc.	Et cetera
FAQ	Frequently Asked Questions
FU	Fixing unit
PR	Professional repairer
HS	Humidity sensor
LS	Level sensor
FW	Firmware
B	Blower
h	Hour
MB C	Main board coded
MB NC	Main board not coded
ICT	Information and communication technology
i. e.	That is to say
JRC	Joint Research Centre
CS	Coolant sensor
CS HE	Coolant sensor heat exchanger
KrWG	German Circular Economy Act (Kreislaufwirtschaftsgesetz)
LU	Laser unit
m	Minute
M	Motor
max.	Maximum
MF	Manufacturer
MC	Motoren capacitators
MOST	Maynard Operation Sequence Technique
MTM	Methods-Time Measurement

n/a	Not available
n/s	No specified information
ONR	Austrian Standardization Program (Österreichische Normungsregel)
P	Pump
PT	Paper tray
PAS	Process air sensor
poss.	Possible
LP	Lay person
ProgRess	German Resource Efficiency Program
RRP	Recommended retail price
s	Second
SFF	Sensor filter flap
CB C	Control board coded
CB NC	Control board not coded
IPSV	Internal power supply unit
D	Door
RDS	Rear drum seal
FDS	Front drum seal
DU	Drum unit
TFR	Transfer roller
DR	Drum bearing
DRV	Driver
DBT	Drum Belt
DLNP	Door locking nose port
DLS	Door lock sensor
HPD	Heat pump dryer
SAS	Subassembly
CL	Closing lid
ASP	Authorised service partner
TG	Target group
IJP	Inkjet printer
LP	Laser printer
EAD	Exhaust air dryer
CDD	Condense dryer

Summary

Electrical and electronic equipment is one of the fastest growing waste streams. The increasing amount of waste is problematic because these devices are complex products consisting of numerous different materials, components, and assemblies, some of which have been generated with a high input of resources and energy. These waste streams can be significantly reduced by extending the service life with the help of increased repairs. Compared with recycling, repairs have the additional advantage that they do not involve the considerable material losses that are often technically unavoidable in recycling. In addition to the ecological advantages, repairs also have economic benefits. Repair can have positive effects at the local level for the labor market and regional value creation.

So far, however, there is no sound scientific basis for determining which factors favor repair and can be defined as a requirement for manufacturers and passed on to customers via labeling. This is where the project “Methods and standards for strengthening material efficiency under the Ecodesign Directive” comes in. Factors favoring repair are being developed for complex products in an interrelationship between theory and empirics. The project pursues the overall objective of strengthening the material efficiency of energy-related products - under the Ecodesign Directive and other product-specific instruments.

The extent to which a defective appliance can be repaired depends on numerous factors. In this project, the focus is on the technical feasibility of a repair, also considering related aspects such as economic and informational aspects.

During the project, different aspects were worked on:

- By participating in several committees within the European standardization mandate M/543 at national and European level, this project contributed to the development of criteria for assessing the repairability, reusability, and upgradeability of energy-related products.
- A system for assessing the repairability of energy-related products (a so-called repairability matrix) has been developed. It aims at providing consumers with information to enable them to make a conscious purchase decision. At the same time, an incentive is created for manufacturers to take repairability into account from the product design stage on.
- The applicability of the repairability matrix has been tested in several case studies using printers and tumble dryers by disassembling selected appliances. The findings will in turn feed into the standardization work and repairability matrix - suggestions have been formulated accordingly.
- Based on the central findings of the project, recommendations have been formulated as to how these findings can be translated into product policy instruments.

Overall, requirements have been developed in the interrelationship between empirics and theory to promote the material efficiency of energy-related products through repair. A repair is a “process of returning a faulty product to a condition where it can fulfil its intended use” (DIN EN 45554). According to DIN EN 45554, a repair is different from an upgrade. An upgrade is a “process to enhance the functionality, performance, capacity or aesthetics of a product” (DIN EN 45554).

Electrical and electronic devices are complex products that are often made up of numerous components. To classify the extent to which a device is repairable, a **conceptual framework** (Chapter 2) is therefore required to reduce this complexity. It is based on four pillars:

a) Priority parts,

b) Indicators,

c) assessment classes, and

d) final label.

To a): **Priority parts** (chapter 2.2) are those parts that typically fail during the normal use of a product. By focusing on these parts when evaluating repairability, the evaluation process can be made much more targeted. There are several options for identifying priority parts. Priority parts can be defined, for example, by the following characteristics:

- frequency with which a part becomes defective,
- functional importance of a part,
- economic value of the part,
- ecological importance of the part, or
- the steps required to disassemble the part.

The mentioned valuation characteristics are usually not congruent. A product part may have the smallest economic value but impact the environment the most. In this report, priority parts are those parts that have functional importance but typically fail during the normal use of a product. It should be noted, however, that only after a product has been on the market for some time it becomes apparent which parts fail frequently, so identifying these parts in advance is difficult to implement.

To b): The extent to which a product is repairable cannot be observed directly. Repairability is primarily a theoretical construct that must be operationalized with the help of measurable **indicators** (chapter 2.3). Key indicators that influence the repairability of products can be divided into two categories: They either relate to the product design (on both: product level and part level, e. g. non-destructive disassembly) or to the repair environment (e. g., tools, information) and thus influence repair indirectly or directly. Furthermore, generic and specific indicators can be distinguished. Generic indicators are very general and can therefore be applied horizontally across various product groups (e. g. duration of availability of spare parts). In contrast, specific indicators concretize the generic indicators depending on the product group and can therefore only be applied to specific product groups (e. g. number of disassembly steps).

To c): The assessment of repairability requires the existence of a **rating system** (chapter 2.4) that classifies repairability. Three systems for assessing repairability can be distinguished:

- qualitative,
- semi-quantitative and
- quantitative systems.

The evaluation systems build on each other with increasing complexity. Which system is used depends on the desired benefit, data availability and practical feasibility. **Qualitative assessments** define indicators that must be fulfilled to classify a product as repairable. They thus represent a checklist that is used to check individually whether the device meets or does not meet the requirement. In a **quantitative assessment**, several individual indicators are combined to form an index that measures the degree to which the product is repairable. It must be decided which indicators should be included in the index and how the dimensions are combined (e. g., additive or multiplicative).

To d): Regardless of the type of rating system, a visibly displayed **label** (chapter 2.5) is required that transparently communicates to customers the assessment achieved regarding the extent to which a product is repairable. Conceivable labels are, for example, an alphabetical or numerical marking. It should be noted, however, that mandatory labeling ensures greater transparency, but does not necessarily result in more sustainable purchasing behavior.

In practice, several approaches to assessing repairability already exist (chapter 3), but they are not universally applied. The existing approaches can be divided into product-specific and generic approaches. Product-specific approaches refer either to specific products (e. g., washing machines, radios) or product groups (e. g., white goods, brown goods), while generic approaches are applicable across product groups, hence horizontally. In general, the product-specific approaches have been in place for some time and the generic approaches only recently. The latter are also striving to develop an overarching evaluation system - and have taken place in parallel with this project in France, Benelux and at the European level.

The **product-specific approaches** (Chapter 3.1) vary between quantitative and qualitative rating systems, as well as a combination of these. First, the *Blue Angel* and the *EU Ecolabel* are examples of qualitative approaches to assessing products, generally addressing their repairability in addition to other environmental impacts. The approaches therefore each contain only individual indicators that refer to whether a product is repairable or not. If all criteria are met, the products tested receive the corresponding seal of approval. Second, unlike qualitative approaches, the primary goal of semi-quantitative approaches is to specifically comparably rank repairability rather than overall environmental friendliness, considering repair aspects. Semi-quantitative approaches include *ONR 192102:2014*, the *iFixit scoring system*, the *Repair Index,* and *repairability.org*. Third, the existing quantitative approaches predominantly address the time required for disassembly. The calculations were originally developed for standardized production processes, which makes them difficult to transfer to individual repair environments. These quantitative approaches include *U-effort, Philips ECC, Desai & Mital, Kroll*.

Current **generic approaches** (Section 3.2) include a study in the context of Benelux by Bracquené et al. (2018), a study by the Joint Research Centre on behalf of the European Commission by Cordella et al. (2018b) and the repair indicator developed in France (French repair index). When this project started, these studies offered a first helpful guidance, but they are mostly theoretical works whose applicability has either not been tested in practice at the start of this study (French repair index, Joint Research Centre study) or only to a limited extent (Benelux study).

Potential repairability indicators (Chapter 4) are taken from the existing product-specific and generic approaches. The analysis shows that a total of 37 indicators can be theoretically used in the following 11 dimensions: Disassembly, Fasteners, Tools, Fault Diagnosis, Information, Spare Parts, Software / Firmware, Knowledge, Working Environment, Data and Password, Manufacturer Service. The individual indicators in these dimensions should not be considered in isolation, but rather are interwoven in complex ways. Although each of the systems for assessing repairability has its specific advantages and disadvantages, the analysis nevertheless reveals several points that must be considered when developing repair indicators:

First, numerous factors influence the extent to which a product can be repaired. They address different aspects of a repair, such as:

- **Economic factors**, e. g., cost of spare parts, cost of tools, cost of labor.

- **Technical factors**, e. g., product design, nondestructive disassembly, access to information.
- **Legal factors**, e. g., guarantee, warranty, availability of safety-related spare parts.
- **Organizational factors**, e. g., availability of repair shops, time required to complete repair, access to information, availability of spare parts.
- **Behavioral factors**, e. g., emotional importance of a product, awareness of repair options, dispensability of a product for repair period.

Second, the assessment of repairability should be based solely on objective criteria that can be verified - rather than subjective criteria. However, objective operationalization of some indicators of repairability is not always possible, although they are theoretically relevant.

Third, an evaluation must be possible at the time a product is placed on the market. This poses a particular challenge, for example, when evaluating the availability of spare parts, because it must be proven that this can be guaranteed in the future for the specified period.

Fourth, although economic factors are often a decisive criterion for whether a repair is carried out at all, this poses a challenge for a uniform evaluation system within the European Union. This is because absolute values are not meaningful, since the costs of repair services, for example, can vary greatly between different member states.

Fifth, there must be continuous monitoring to check the extent to which the information provided is accurate, especially if the classification of repairability is made exclusively by the manufacturing company.

As part of this project, case studies were carried out on two product groups – printers and tumble dryers – to check whether the theoretical indicators describe their repairability and, if so, which of them can be used for an assessment.

Within the two product groups, inkjet and laser printers as well as exhaust air, condensing and heat pump dryers were investigated. For the two product groups in the case studies, current models from manufacturers with relevant market shares that topped the sales lists of major Internet retailers were selected.

Priority parts were selected based on literature research, an informal survey of repairers, and consultation with the client.

For each product group, a practical and a theoretical part of the case studies were conducted. During the practical work, all priority parts were disassembled, and indicators were quantified. To exclude learning effects during the case studies, the practical work was carried out by experienced technicians and designed, accompanied and documented by scientific staff. Indicators examined in the practical part of the case studies included:

- Disassembly depth (number of work steps),
- Disassembly time,
- Type and number of fastening elements (BFE),
- Visibility of fastening elements (by random sample),
- Number of tools,
- Number of tool changes,

- Tool class,
- Necessary knowledge, and
- Working environment.

The indicators working environment, fastener visibility, and necessary knowledge could not be operationalized in the case studies, as no quantifiable indicator could be found. Therefore, these indicators are not included in the optimized repairability matrix even though these indicators may be relevant as well.

Regarding tools, it became clear that repair operations can almost always be performed with a variety of possible tools. A general classification of tools into classes that are more or less available or suitable is therefore not recommended. Instead, a negative evaluation should be made within the framework of a repairability matrix if an operation requires a tool that is not commercially available for all actors - i. e., also for private individuals. The indicators tool change and number of tools are not included in the optimized repairability matrix.

Regarding the fastening elements, the type of chosen fastener proved to be relevant. It should be reusable or removable, with reusability being rated better.

For both number of fasteners and number of steps, a linear relationship to disassembly time was found during the case studies. Both indicators can therefore potentially be used as a proxy for disassembly time in a rating system to make the rating system also applicable without having to perform extensive serial tests on equipment each time. In the optimized repairability matrix, the number of work steps is adopted because the mathematical relationship with disassembly time is stronger for individual product groups.

As a further indicator for tumble dryers, the detachability of the side panels is derived from the case studies conducted. It has been shown that the disassembly times of tumble dryers are lower whereas many side panels as possible could be removed independently of any other side panel. This is evaluated in the indicator.

Based on the results of practical investigations, the following indicators are selected:

- Number of work steps (disassembly depth),
- Type of fastening,
- Tools, and
- Detachability of side panels (for large household appliances / tumble dryers).

Theoretical research was conducted on selected indicators that could not be tested directly on the appliances.

The following indicators were examined as part of the theoretical research:

- Availability of repair information (per target group),
- Type of user interface / interface for fault diagnosis,
- Identifiability of spare parts,
- Availability of spare parts (per target group) (by random sample),
- Spare parts delivery time (by random sample),

- Spare parts costs (by random sample),
- Availability of software / firmware (per target group), and
- Reset / restore factory settings.

The following sources of information were used for the research:

- Internet sites of manufacturers or their designated contractors,
- Product documents (user manuals, etc.), and
- Written and telephone inquiries to manufacturers or their designated contractors.

Information sources were used in a cascading fashion wherever appropriate. That is, inquiries and requests were made when the relevant information was not already publicly available.

Only service and information offers from the manufacturer or authorized third parties were considered in the research. Offers from independent third parties (e. g. independent Internet platforms on which repair manuals are sold) are not evaluated.

Furthermore, it soon became clear that manufacturers and contractors treat requests from different stakeholders differently. For this reason, actors are divided into three target groups for the case studies and the optimized evaluation matrix:

- Private individuals: Laypersons, without electrotechnical training.
- Competent repairers: persons with electrical engineering training who are not contractually affiliated with the manufacturer or designated as service partners.
- Contractual partner(s) of the manufacturer: persons with electrotechnical training who are contractually associated with the manufacturer or are designated as service partners.

All indicators considered have proven to be relevant in the theoretical research and will be included in the optimized repairability matrix. However, "Identifiability of spare parts" is not adopted as a single indicator. Instead, the availability of exploded views, which allow the identification of spare parts, is assessed as a sub-aspect of "availability of information".

Two additional indicators are derived from the theoretical indicators to complement the previously selected ones. With the "spare parts policy of the manufacturer", it is evaluated whether manufacturers make groups of spare parts unavailable for individual target groups or not. In addition, the duration of spare parts availability is included in the optimized repairability matrix.

Thus, based on the results of the theoretical research, the following indicators are selected:

- Availability of spare parts,
- Spare parts policy of the manufacturer with regard to the model,
- Duration of availability of spare parts,
- Delivery time for spare parts,
- Cost of spare parts,
- Availability of repair information,

- Possibility of fault diagnosis,
- Availability of updated software / firmware, and
- Possibility of resetting to factory settings (for electronic devices / printers).

Based on the case studies, rating classes were derived for the indicators, which represent the ranges found for the devices investigated. The optimized repairability matrix with its rating classes and scoring is summarized in Table 1 below.

Table 1: Optimized repairability matrix

Indicator	Assessment level	Valuation classes	Point scale
Disassembly depth	Parts	A: The number of work steps required is ≤ 70% of the mean value B: The number of work steps required is > 70 to ≤ 90% of the mean value C: The number of work steps required is > 90 to ≤ 110% of the mean value D: The number of work steps required is > 110 to ≤ 130% of the mean value E: The number of work steps required is > 130% of the mean value	A = 10 B = 7 C = 4 D = 1 E = 0
Fastener type	Parts	A: Reusable B: Removable C: Neither reusable nor removable	A = 10 B = 5 C = 0
Tool type	Parts	A: Repair possible without tools, with standard tools commercially available to lay persons, or with tools supplied B: Repair possible with specific tools that are not supplied but can be purchased by professional repairer C: Repair possible with specific tools that are not supplied but can be purchased by authorised service partners D: Repair cannot be carried out with any tool	A = 10 B = 7 C = 3 D = 0
Detachability of side panels	Device	A: Four panels of the tumble dryer can be removed individually B: Three panels of the tumble dryer can be removed individually C: Two panels of the tumble dryer can be removed individually D: One panel of the tumble dryer can be removed individually	A = 10 B = 7 C = 4 D = 1
Manufacturer's spare parts policy for the model	Device	For lay persons: A: Non-safety-relevant spare parts and safety-relevant spare parts are available B: Only non-safety-relevant spare parts are available C: No spare parts are available	A = 10 B = 5 C = 0

Indicator	Assessment level	Valuation classes	Point scale
		For professional repairers: A: Non-safety related spare parts and safety related spare parts are available B: Only non-safety related spare parts are available C: No spare parts are available For authorised service partners of the manufacturer / the manufacturer: A: Non-safety related spare parts and safety related spare parts are available B: Only non-safety related spare parts are available C: No spare parts are available	 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0
Availability of spare parts	Parts	A: The spare part is available for lay persons, professional repairers, and authorised service partners / manufacturers B: The spare part is available for professional repairer and authorised service partners / manufacturers C: The spare part is only available for authorised service partners/manufacturers D: The spare part is not available	A = 10 B = 7 C = 3 D = 0
Duration of availability of spare parts	Device	A: Long-term availability (≥ 10 years for printers and ≥ 15 years for dryers after placing the last unit of a product model on the market) B: Medium-term availability (> 2 to < 10 years for printers and > 2 to < 15 years for dryers, after placing the last unit of a product model on the market) C: Short-term availability or no availability (≤ 2 years for printers as well as dryers after placing the last unit of a product model on the market)	A = 10 B = 5 C = 0
Delivery time for spare parts	Parts	A: ≤ 4 working days B: 5 to 14 working days C: 15 to 21 working days D: ≥ 22 working days	A = 10 B = 7 C = 4 D = 1
Cost of spare parts	Parts	Assemblies: A: ≤ 20% of the RRP of the product at the time the device was placed on the market B: >20 to < 50% of the RRP of the product at the time the device was placed on the market C: ≥ 50% of the RRP of the product at the time the device was placed on the market Subassemblies: A: ≤10% of the RRP of the product at the time the device was placed on the market B: > 10 to < 20% of the RRP of the product at the time the device was placed on the market	 A = 10 B = 5 C = 1 A = 10 B = 5

Indicator	Assessment level	Valuation classes	Point scale
		C: ≥ 20% of the RRP of the product at the time the device was placed on the market Components: A: ≤ 5% of the RRP of the product at the time the device was placed on the market B: > 5 to < 10% of the RRP of the product at the time the device was placed on the market C: ≥ 10% of the RRP of the product at the time the device was placed on the market	C = 1 A = 10 B = 5 C = 1
Availability of information	Device	For lay persons: A: Comprehensive information is available B: Basic information is available C: No information is available For professional repairers: A: Comprehensive information is available B: Basic information is available C: No information is available For authorised service partners of the manufacturer / the manufacturer: A: Comprehensive information is available B: Basic information is available C: No information is available	A = 10 B = 5 C = 0 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0
Fault diagnosis	Device	A: Intuitive interface: Error is communicated with a signal that is understood without external accompanying documentation. B: Coded interface with public reference table: Error can be read out via interface in conjunction with supplied or publicly available accompanying documentation, (e. g., error code table). C: Publicly available hardware/software interface: Publicly available hardware and/or software is required to read out the error. D: Proprietary interface: Proprietary hardware and/or software is required to read out the error and is not supplied with the product. E: Not possible with any interface type.	A = 10 B = 7 C = 4 D = 1 E = 0
Firmware	Device	A: Updated firmware provided for ≥ 10 years for printers and ≥ 15 years for dryers after the placing on the market of the last unit of a product model B: Updated firmware provided for > 2 to < 10 years for printers and >2 to < 15 years for dryers after the placing on the market of the last unit of a product model C: Updated firmware provided ≤ 2 years for printers and dryers after the placing on the market of the last unit of a product model	A = 10 B = 5 C = 0

Indicator	Assessment level	Valuation classes	Point scale
Driver (Only for printers)	Device	A: Updated driver provided for ≥ 10 years for all relevant operating systems after the placing on the market of the last unit of a product model (Windows, macOS, Linux) B: Updated driver provided for ≥ 10 years for all originally supported operating systems after the placing on the market of the last unit of a product model C: Updated driver provided < 10 years after the placing on the market of the last unit of a product model	A = 10 B = 5 C = 0
Restoring of factory settings and resetting passwords (Only for printers)	Device	A: Restoring factory settings and resetting passwords is possible with the help of a function integrated in the device. B: Restoration of factory settings and resetting of passwords is possible with the help of freely accessible hardware or software. C: Restoration of factory settings and resetting of passwords is only possible with the help of the manufacturer's authorised service partners / the manufacturer (service reset). D: Restoration of factory settings and resetting of passwords is not possible.	A = 10 B = 5 C = 1 D = 0

Source: Own depiction

In order to check the applicability of the optimized repairability matrix, it was tested on two laser printers and two heat pump dryers, which were also part of the case studies.

In order to convert the evaluation classes into a numerical value for repairability, the instrument of a utility value analysis was chosen. This was first used to identify or calculate (as average value from the values of all priority parts) the partial benefits for each indicator, which were then combined into utility values for each appliance. All indicators and spare parts were weighted equally. With the utility analysis used, it is possible at any time to give different weights to the indicators and spare parts.

Two relatively similar laser printers from one manufacturer were selected for testing the repairability matrix. It was expected that the utility values (values indicating the repairability) of these two devices would be close to each other (Hypothesis 1).

To test a different case, two heat pump dryers from different manufacturers were selected, which, according to the results of the case studies, differed greatly in their repairability. For these two appliances, it was expected that the difference between the utility values would be larger than for the printers (Hypothesis 2). Furthermore, it was expected that whatever device was more repairable according to the case study results (e. g., in terms of low disassembly times and a generous supply of spare parts by the manufacturer) would achieve a higher utility value (Hypothesis 3).

By applying the repairability matrix, all three hypotheses were confirmed. Therefore, the optimized repairability matrix maps the results of the case studies. Therefore, it is stated that the matrix is suitable to evaluate the repairability of devices. Thereby, the expected differences between the devices are mapped.

Based on the preceding theoretical and empirical findings of this project, **measures to strengthen repair** (Chapter 7) are finally formulated. To this end, an **inventory of measures** (Chapter 7.1) is first conducted to determine the extent to which repair is currently promoted in key policy programs. The analysis clearly shows that several political programs already refer to the need to increase resource efficiency by promoting repair through various measures. So far, however, the main lack is a concretization of these measures. Therefore, **recommendations for measures** (Chapter 7.2) to promote repair that can be integrated into product policy instruments such as the Blue Angel and the Ecodesign Directive are then formulated. The requirements can vary depending on whether they are needed for market entry or for labels with higher requirements. The recommended measures include for example:

- The number of **steps required** to dismantle tumble dryers and printers must be ≤ 70% of the mean value.
- The **fasteners** used must be reusable.
- Repair must be possible without **tools**, with standard tools commercially available for lay persons, or with tools provided.
- The duration of availability of **spare parts** shall be ≥ 10 years for printers and ≥ 15 years for tumble dryers after the last device has been placed on the market.
- Non-safety-relevant spare parts and safety-relevant spare parts must be available for private persons, professional repairers and contract partners/manufacturers.
- **Spare parts** must be delivered within 4 working days.
- Regarding **spare parts prices**, sub-assemblies must cost ≤ 20% of the RRP of the product at the time the device was placed on the market. Subassemblies must cost ≤ 10% of the RRP of the product at the time the device was placed on the market. Components must cost ≤ 5% of the RRP of the product at the time the device was placed on the market.
- Comprehensive **information** shall be available for lay persons, professional repairers and authorised service partners of the manufacturer. Comprehensive information includes error code tables, exploded views, circuit diagrams and repair manuals.
- For **fault diagnosis**, the error must be communicated with a signal that can be understood without external accompanying documents.
- Necessary **firmware** updates must be available for ≥ 10 years for printers and ≥ 15 years for dryers after the last model has been placed on the market.
- For printers, **driver updates** must be provided for all originally supported operating systems for ≥ 10 years after the after the placing on the market of the last unit of a product model.
- For printers, it must be possible to **restore factory settings and reset passwords** using the built-in functions of the device.
- For tumble dryers, each of the four **side panels** must be detachable independently of all other side panels.

The findings obtained in this project point to further research needs (Chapter 8), which are identified in conclusion, such as:

- The applicability of the developed repair matrix should be verified in further case studies other than tumble dryers and printers.
- The assessment classes determined for the “work steps” indicator require reference values, which should be determined for further product groups via practical studies.
- Regarding the priority parts, sample studies should be carried out at regular intervals to determine which parts are currently present in the equipment on the market.
- In addition to the technical aspects developed in this project, e. g. types of fastening and tools, it should be analyzed to what extent a label for repairability influences the purchase decision and under which circumstances consumers repair defective devices today.

Zusammenfassung

Elektrische und elektronische Geräte bilden einen der am schnellsten wachsenden Abfallströme. Die steigende Abfallmenge ist problematisch, da es sich bei diesen Geräten um komplexe Produkte handelt, die aus zahlreichen unterschiedlichen Stoffen, Bauteilen und Baugruppen bestehen, die mit teils hohem Ressourcen- und Energieaufwand gewonnen wurden. Diese Abfallströme können durch Lebensdauerverlängerung mithilfe verstärkter Reparaturen deutlich reduziert werden. Gegenüber dem Recycling haben Reparaturen den zusätzlichen Vorteil, dass hierbei nicht die teils erheblichen Stoffverluste auftreten, die beim Recycling oft auch technisch unvermeidlich sind. Eine Reparatur ist neben den ökologischen auch mit ökonomischen Vorteilen verbunden. Die Reparatur kann positive Effekte auf lokaler Ebene für den Arbeitsmarkt und die regionale Wertschöpfung entfalten.

Bisher fehlt jedoch eine fundierte wissenschaftliche Basis, welche Faktoren eine Reparatur begünstigen und als Anforderung an Hersteller festgelegt und über eine Kennzeichnung an Kund*innen weitergegeben werden können. An dieser Stelle setzt das Vorhaben „Methoden und Normen zur Stärkung der Materialeffizienz unter der Ökodesign-Richtlinie“ an. Es werden für komplexe Produkte reparaturbegünstigende Faktoren im Wechselverhältnis zwischen Theorie und Empirie erarbeitet. Das Vorhaben verfolgt das übergeordnete Ziel, die Materialeffizienz von energieverbrauchsrelevanten Produkten zu stärken – unter der Ökodesign-Richtlinie und weiteren produktspezifischen Instrumenten.

Inwiefern ein defektes Gerät repariert werden kann, hängt von zahlreichen Faktoren ab. In diesem Vorhaben steht die technische Realisierbarkeit einer Reparatur im Mittelpunkt unter Berücksichtigung von damit verbundenen Aspekten, wie zum Beispiel ökonomischen und informatorischen.

Im Rahmen des Vorhabens wurden unterschiedliche Aspekte bearbeitet:

- Durch die Mitarbeit in mehreren Gremien im Rahmen des europäischen Normungsmandats M/543 auf nationaler und europäischer Ebene wurde unter anderem an der Erarbeitung von Kriterien zur Bewertung der Reparier-, Wiederverwend- und Upgradebarkeit energieverbrauchsrelevanter Produkte mitgearbeitet.
- Es wurde ein System zur Bewertung der Reparierbarkeit von energieverbrauchsrelevanten Produkten (eine sogenannte Reparierbarkeitsmatrix) entwickelt. Dieses zielt darauf ab, Konsumentinnen und Konsumenten Informationen zur Verfügung zu stellen, um auf dieser Basis eine bewusste Kaufentscheidung treffen zu können. Gleichzeitig wird ein Anreiz für Hersteller erzeugt, bereits beim Produktdesign die Reparierbarkeit zu berücksichtigen.
- Die Anwendbarkeit der Reparierbarkeitsmatrix wurde in Fallstudien anhand von Druckern und Wäschetrocknern[1] durch die Demontage ausgewählter Geräte überprüft. Die Erkenntnisse sollen wiederum in die Normungsarbeit und Reparierbarkeitsmatrix fließen – entsprechende Vorschläge wurden im Vorhaben erarbeitet.
- Basierend auf den zentralen Erkenntnissen des Vorhabens wurden abschließend Empfehlungen formuliert, wie diese Erkenntnisse in produktpolitische Instrumente überführt werden können.

Insgesamt wurden somit im Wechselverhältnis zwischen Empirie und Theorie Anforderungen erarbeitet, um die Materialeffizienz von energieverbrauchsrelevanten Produkten durch eine Re-

[1] Die Begriffe „Wäschetrockner“ und „Trockner“ werden in diesem Bericht synonym verwendet.

paratur zu fördern. Eine Reparatur ist ein „Prozess, bei dem ein fehlerhaftes Produkt wieder in einen Zustand gebracht wird, bei dem es seine bestimmungsgemäße Verwendung erfüllen kann“ (DIN EN 45554). Gemäß DIN EN 45554 unterscheidet sich eine Reparatur von einem Upgrade. Ein Upgrade ist ein „Prozess der Steigerung der Funktionalität, Leistung, Kapazität oder Ästhetik eines Produkts“ (DIN EN 45554).

Elektrische und elektronische Geräte sind komplexe Produkte, die sich oft aus zahlreichen Komponenten zusammensetzen. Zur Einstufung, inwiefern ein Gerät reparierbar ist, ist daher ein **konzeptioneller Rahmen** (Kapitel 2) erforderlich, der diese Komplexität reduziert. Er basiert auf vier Säulen:

a) Prioritäre Teile,

b) Indikatoren,

c) Bewertungsklassen und

d) finalem Label.

Zu a): **Prioritäre Teile** (Kapitel 2.2) sind jene Teile, die typischerweise im Rahmen der üblichen Nutzung eines Produkts ausfallen. Indem diese Teile bei der Bewertung der Reparierbarkeit im Fokus stehen, lässt sich der Bewertungsprozesses deutlich zielgerichteter gestalten. Um prioritäre Teile zu identifizieren, gibt es verschiedene Optionen. Prioritäre Teile können zum Beispiel definiert werden über folgende Eigenschaften:

- Häufigkeit, mit der ein Teil defekt wird,
- funktionale Wichtigkeit eines Teils,
- ökonomischer Wert des Teils,
- ökologische Bedeutung des Teils oder
- die erforderlichen Schritte zur Demontage des Teils.

Die genannten Bewertungseigenschaften sind in der Regel nicht deckungsgleich, beispielsweise kann ein Produktteil den kleinsten ökonomischen Wert haben, aber die Umwelt am meisten belasten. In diesem Bericht sind prioritäre Teile jene Teile, die eine funktionale Wichtigkeit haben, aber typischerweise im Rahmen der üblichen Nutzung eines Produkts ausfallen. Dabei muss beachtet werden, dass erst nachdem ein Produkt über einen längeren Zeitraum auf dem Markt ist, ersichtlich wird, welche Teile oft ausfallen, sodass eine Identifikation dieser Teile vorab schwer umzusetzen ist.

Zu b): Inwiefern ein Produkt reparierbar ist, kann nicht direkt beobachtet werden. Reparierbarkeit ist zunächst ein theoretisches Konstrukt, das mithilfe von messbaren **Indikatoren** (Kapitel 2.3) operationalisiert werden muss. Zentrale Indikatoren, welche die Reparierbarkeit von Produkten beeinflussen, lassen sich in zwei Kategorien unterteilen: Sie beziehen sich entweder auf das Produktdesign (sowohl auf Ebene der Teile als auch der Geräte, z. B. zerstörungsfreie Demontage) oder auf die Reparaturumgebung (z. B. Werkzeuge, Informationen) und beeinflussen die Reparatur somit mittelbar oder unmittelbar. Des Weiteren können generische und spezifische Indikatoren unterschieden werden. Generische Indikatoren sind allgemein gehalten und können daher horizontal, über diverse Produktgruppen hinweg, angewendet werden (z. B. Dauer der Verfügbarkeit von Ersatzteilen). Dem hingegen konkretisieren spezifische Indikatoren die generischen Indikatoren in Abhängigkeit von der Produktgruppe und sind dementsprechend nur produktgruppenspezifisch anwendbar (z. B. Anzahl der Demontageschritte).

Zu c): Die Bewertung der Reparierbarkeit setzt schlussendlich die Existenz eines **Bewertungssystems** (Kapitel 2.4) voraus, dass die Reparierbarkeit einstuft. Drei Systeme zur Bewertung der Reparierbarkeit können unterschieden werden:

- qualitative,
- semi-quantitative und
- quantitative Systeme.

Die Bewertungssysteme bauen mit zunehmender Komplexität aufeinander auf. Welches System verwendet wird, hängt von dem erwünschten Nutzen, der Datenverfügbarkeit und der praktischen Umsetzbarkeit ab. Bei **qualitativen Bewertungen** werden Indikatoren definiert, die zwingend erfüllt sein müssen, um ein Produkt als reparierbar einzustufen. Sie stellen somit eine Checkliste dar, mit deren Hilfe einzeln geprüft wird, ob das Gerät die Anforderung erfüllt oder nicht erfüllt. Bei einer **quantitativen Bewertung** werden mehrere Einzelindikatoren zu einem Index zusammengeführt, der den Grad der Reparierbarkeit des Produkts misst. Dabei ist zu entscheiden, welche Indikatoren in den Index eingehen sollen und wie die Dimensionen miteinander kombiniert werden (z. B. additiv oder multiplikativ).

Zu d): Unabhängig von der Art des Bewertungssystems ist ein sichtbar angebrachtes **Label** (Kapitel 2.5) erforderlich, das die erzielte Bewertung, inwiefern ein Produkt reparierbar ist, transparent an Kundinnen und Kunden kommuniziert. Denkbare Labels sind zum Beispiel eine alphabetische oder numerische Kennzeichnung. Es muss jedoch angemerkt werden, dass eine Kennzeichnungspflicht für mehr Transparenz sorgt, allerdings nicht zwangsläufig auch ein nachhaltigeres Kaufverhalten nach sich zieht.

In der Praxis existieren bereits mehrere Ansätze zur Bewertung der Reparierbarkeit (Kapitel 3), die jedoch keine allumfassende Anwendung finden. Die bestehenden Ansätze lassen sich unterteilen in produktspezifische und generische Ansätze. Produktspezifische Ansätze beziehen sich entweder auf konkrete Produkte (z. B. Waschmaschinen, Radios) oder Produktgruppen (z. B. Weiße Ware, Braune Ware), während generische Ansätze produktgruppenübergreifend, folglich horizontal, anwendbar sind. Generell existieren die produktspezifischen Ansätze bereits seit längerer und die generischen Ansätze erst seit kurzer Zeit. Letztere bemühen sich ebenfalls um die Entwicklung eines übergeordneten Bewertungssystems – und fanden parallel zu diesem Vorhaben in Frankreich, Benelux und auf europäischer Ebene statt.

Die **produktspezifischen Ansätze** (Kapitel 3.1) variieren zwischen quantitativen und qualitativen Bewertungssystemen sowie einer Kombination aus diesen. Erstens: der *Blaue Engel* und das *EU Ecolabel* sind Beispiele für qualitative Ansätze zur Bewertung von Produkten, bei denen neben Umweltwirkungen wie dem Energieverbrauch auch deren Reparierbarkeit adressiert wird. Die Ansätze enthalten jeweils nur einzelne Indikatoren, die darauf verweisen, ob ein Produkt reparierbar ist oder nicht. Werden alle Kriterien insgesamt erfüllt, erhalten die geprüften Produkte das entsprechende Gütesiegel. Zweitens: Im Gegensatz zu den qualitativen Ansätzen besteht das vorrangige Ziel der semi-quantitativen Ansätze darin, speziell die Reparierbarkeit vergleichbar einzustufen und nicht die Umweltfreundlichkeit insgesamt unter Berücksichtigung von Reparaturaspekten. Unter semi-quantitative Ansätze fallen die *ONR 192102:2014, das iFixit Scoring System, der Repairability Indicator und repairability.org.* Drittens: Die existierenden quantitativen Ansätze adressieren überwiegend die Zeit, die für Demontage benötigt wird. Die Berechnungen wurden ursprünglich für standardisierte Produktionsverfahren entwickelt, was eine Übertragbarkeit auf individuelle Reparaturumgebungen erschwert. Zu diesen quantitativen Ansätzen zählen *U-effort, Philips ECC, Desai & Mital, Kroll*.

Zu den aktuellen **generische Ansätzen** (Kapitel 3.2) zählen eine Studie im Kontext der Benelux-Staaten von Bracquené et al. (2018), eine Studie des Joint Research Centre im Auftrag der Europäischen Kommission von Cordella et al. (2018b) sowie der in Frankreich entwickelte Reparatur-Index (Indice de réparabilité). Sie boten zu Beginn dieses Projekts eine erste hilfreiche Orientierung, jedoch handelt es sich überwiegend um theoretische Arbeiten, deren Anwendbarkeit zu Beginn des Projektes entweder nicht (Französischer Reparaturindex, Studie des Joint Research Centre) oder nur in geringem Umfang (Benelux-Studie) praktisch überprüft wurden.

Den bestehenden produktspezifischen und generischen Ansätzen werden **potenzielle Reparierbarkeitsindikatoren** (Kapitel 4) entnommen. Die Analyse zeigt, dass insgesamt 37 Indikatoren in folgenden 11 Dimensionen theoretisch verwendet werden können: Demontage, Befestigungen, Werkzeuge, Fehlerdiagnose, Informationen, Ersatzteile, Software/Firmware, Kenntnisse, Arbeitsumgebung, Daten und Passwort, Herstellerservice. Die einzelnen Indikatoren in diesen Dimensionen dürfen nicht isoliert betrachtet werden, sondern sind vielmehr auf komplexe Art und Weise miteinander verwoben. Auch wenn jedes der genannten Systeme zur Bewertung der Reparierbarkeit ihre spezifischen Vor- und Nachteile hat, zeigt die Analyse dennoch mehrere Punkte, die bei der Erarbeitung von Reparaturindikatoren beachtet werden müssen:

Erstens: Zahlreiche Faktoren beeinflussen, inwiefern ein Produkt repariert werden kann. Sie adressieren unterschiedliche Aspekte einer Reparatur, wie zum Beispiel:

- Ökonomische Faktoren, z. B. Kosten für Ersatzteile, Kosten für Werkzeuge, Kosten für Arbeitsleistung.
- Technische Faktoren, z. B. Produktdesign, zerstörungsfreie Demontage, Zugang zu Informationen.
- Rechtliche Faktoren: z. B. Garantie, Gewährleistung, Verfügbarkeit von nicht sicherheitsrelevanten und sicherheitsrelevanten Ersatzteilen.
- Organisatorische Faktoren, z. B. Verfügbarkeit von Reparaturwerkstätten, Zeitaufwand für Abwicklung der Reparatur, Zugang zu Informationen, Verfügbarkeit von Ersatzteilen.
- Verhaltensrelevante Faktoren, z. B. emotionale Bedeutung eines Produkts, Bewusstsein für Reparaturmöglichkeiten, Entbehrlichkeit eines Produktes für Reparaturzeitraum.

Zweitens: die Bewertung der Reparierbarkeit sollte ausschließlich auf objektiven Kriterien beruhen, die verifizierbar sind. Obwohl einige Indikatoren für eine Reparatur theoretisch relevant sind, ist eine objektive Operationalisierung jedoch nicht immer möglich.

Drittens: es muss zum Zeitpunkt, an dem ein Produkt auf dem Markt platziert wird, eine Bewertung möglich sein. Dies stellt zum Beispiel eine besondere Herausforderung bei der Bewertung der Verfügbarkeit von Ersatzteilen dar, weil nachgewiesen werden muss, dass diese in Zukunft für den angegebenen Zeitraum gewährleistet werden kann.

Viertens: ökonomische Faktoren sind häufig zwar ein ausschlaggebendes Kriterium dafür, ob eine Reparatur überhaupt durchgeführt wird, allerdings stellt dies für ein einheitliches Bewertungssystem innerhalb der Europäischen Union eine Herausforderung dar, denn absolute Werte sind nicht sinnvoll, da beispielsweise die Kosten für Reparaturdienstleistungen zwischen den Mitgliedsstaaten stark variieren können.

Fünftens: es muss ein kontinuierliches Monitoring geben, bei dem überprüft wird, inwiefern die gemachten Angaben zutreffen, insbesondere sofern die Einstufung der Reparierbarkeit ausschließlich durch das herstellende Unternehmen erfolgt.

Als Teil dieses Projektes wurden **Fallstudien** an zwei Produktgruppen – Drucker und Wäschetrockner – durchgeführt, um zu überprüfen, ob und wenn ja, welche der theoretischen Indikatoren die Reparaturfähigkeit dieser und ggfs. weiterer energieverbrauchsrelevanter Geräte beschreiben und für eine Bewertung herangezogen werden können.

Innerhalb der beiden Produktgruppen wurden Tintenstrahl- und Laserdrucker sowie Abluft-, Kondens- und Wärmepumpentrockner untersucht. Für die beiden Produktgruppen der Fallstudien wurden aktuelle Modelle von Herstellern mit relevanten Marktanteilen ausgewählt, welche die Verkaufslisten der großen Internethändler anführten.

Die prioritären Teile wurden auf der Basis von Literaturrecherchen, einer informellen Befragung von Reparaturbetrieben und der Abstimmung mit dem Auftraggeber ausgewählt.

Für jede Produktgruppe wurden ein praktischer und ein theoretischer Teil der Fallstudien durchgeführt. Während der praktischen Arbeiten wurden alle prioritären Teile demontiert und Indikatoren soweit möglich quantitativ erfasst. Um Lerneffekte im Verlauf der Fallstudien auszuschließen, wurden die praktischen Arbeiten von erfahrenen Techniker*innen durchgeführt und von wissenschaftlichen Mitarbeiter*innen konzipiert, begleitet und dokumentiert. Zu den Indikatoren, die im praktischen Teil der Fallstudien untersucht wurden, zählen:

- Demontagetiefe (Anzahl Arbeitsschritte),
- Demontagezeit,
- Art und Anzahl der Befestigungselemente (BFE),
- Sichtbarkeit der Befestigungselemente (stichprobenartig),
- Anzahl Werkzeuge,
- Anzahl Werkzeugwechsel,
- Werkzeugklasse,
- notwendige Kenntnisse und
- Arbeitsumgebung.

Die Indikatoren Arbeitsumgebung, Sichtbarkeit von Befestigungselementen und die Notwendigen Kenntnisse erwiesen sich im Rahmen der Fallstudien als nicht operationalisierbar, da keine sinnvollen bzw. quantifizierbaren Bewertungskriterien gefunden wurden. Daher werden diese Indikatoren nicht in die entwickelte optimierte Reparierbarkeitsmatrix übernommen, auch wenn diese Indikatoren grundsätzlich relevant sein können.

In Bezug auf Werkzeuge wurde deutlich, dass Reparaturoperationen fast immer mit einer Vielzahl möglicher Werkzeuge durchgeführt werden können. Eine generelle Einteilung von Werkzeugen in Klassen, die besser oder schlechter verfügbar oder geeignet sind, wird daher nicht empfohlen. Stattdessen sollte im Rahmen einer Reparierbarkeitsmatrix eine negative Bewertung erfolgen, wenn für eine Operation ein Werkzeug erforderlich ist, das nicht für alle Akteur*innen – also auch für Privatpersonen – im Handel zu beziehen ist. Die Indikatoren Werkzeugwechsel und -anzahl werden nicht in die optimierte Reparierbarkeitsmatrix übernommen.

In Bezug auf die Befestigungselemente erwies sich die Art der gewählten Befestigung als relevant. Diese sollte wiederverwendbar oder entfernbar sein, wobei die Wiederverwendbarkeit besser bewertet werden sollte.

Sowohl bei der Anzahl der Befestigungselemente als auch bei der Zahl der Arbeitsschritte wurde im Rahmen der Fallstudien ein linearer Zusammenhang zur Demontagezeit festgestellt. Beide Indikatoren können daher potenziell in einem Bewertungssystem stellvertretend für die Demontagezeit stehen, um das Bewertungssystem anwendbar zu machen, ohne jedes Mal umfangreiche Reihenuntersuchungen an Geräten durchführen zu müssen. In die optimierte Reparierbarkeitsmatrix wird die Zahl der Arbeitsschritte übernommen, da der mathematische Zusammenhang mit der Demontagezeit bei einzelnen Produktgruppen stärker ist.

Als weiterer Indikator für Wäschetrockner wird aus den durchgeführten Fallstudien die Lösbarkeit der Seitenwände abgeleitet. Es hat sich gezeigt, dass die Demontagezeiten der Wäschetrockner geringer sind, bei denen möglichst viele Seitenwände unabhängig von jeder anderen Seitenwand entfernt werden können. Dies wird in dem Indikator bewertet.

Aufgrund der Ergebnisse der praktischen Untersuchungen werden die folgenden Indikatoren ausgewählt:

- Zahl der Arbeitsschritte (Demontagetiefe),
- Befestigungsart,
- Werkzeuge und
- Lösbarkeit der Seitenwände (für Haushaltsgroßgeräte / Wäschetrockner).

Die theoretischen Recherchen erfolgten zu ausgewählten Indikatoren, die nicht direkt an den Geräten getestet werden konnten.

Folgende Indikatoren wurden im Rahmen der theoretischen Recherchen untersucht:

- Verfügbarkeit von Reparaturinformationen (pro Zielgruppe),
- Art der Benutzeroberfläche / Schnittstelle zur Fehlerdiagnose,
- Identifizierbarkeit von Ersatzteilen,
- Ersatzteilverfügbarkeit (pro Zielgruppe) (stichprobenartig),
- Lieferzeit Ersatzteile (stichprobenartig),
- Kosten der Ersatzteile (stichprobenartig),
- Verfügbarkeit Software / Firmware (pro Zielgruppe) und
- Möglichkeit des Reset / Wiederherstellen der Werkseinstellungen.

Für die Recherchen wurden folgende Informationsquellen genutzt:

- Internetseiten von Herstellern oder von ihnen benannten Vertragspartnern,
- Produktdokumente (Benutzerhandbücher etc.) und
- schriftliche und telefonische Anfragen bei den Herstellern oder von ihnen benannten Vertragspartnern.

Die Informationsquellen wurden, wo immer sinnvoll, kaskadierend genutzt. D. h. Anfragen und Nachfragen erfolgten dann, wenn die entsprechenden Informationen nicht bereits öffentlich zur Verfügung gestellt wurden. Im Rahmen der Recherchen wurden nur Service- und Informationsangebote des Herstellers oder autorisierter Dritter betrachtet. Angebote von unabhängigen Dritten (z. B. unabhängige Internetplattformen, auf denen Reparaturanleitungen vertrieben werden) wurden nicht bewertet.

Weiterhin wurde sehr schnell deutlich, dass Hersteller und Vertragspartner Anfragen von verschiedenen Akteur*innen unterschiedlich behandeln. Daher werden Akteur*innen für die Fallstudien und die optimierte Bewertungsmatrix in drei Zielgruppen unterschieden:

- Privatpersonen: Laien, ohne elektrotechnische Ausbildung.
- Fachlich kompetente(r) Reparateur*in: Personen, mit elektrotechnischer Ausbildung, die nicht vertraglich mit dem Hersteller verbunden oder als Servicepartner benannt sind.
- Vertragspartner des Herstellers / der Hersteller: Personen mit elektrotechnischer Ausbildung, die mit dem Hersteller vertraglich verbunden sind oder als Servicepartner benannt sind.

Alle betrachteten Indikatoren haben sich im Rahmen der theoretischen Recherchen als relevant erwiesen und werden in die optimierte Reparierbarkeitsmatrix übernommen. Die „Identifizierbarkeit von Ersatzteilen“ wird allerdings nicht als einzelner Indikator übernommen. Stattdessen wird die Verfügbarkeit von Explosionszeichnungen, durch die Ersatzteile identifiziert werden können, als ein Teilaspekt der „Verfügbarkeit von Informationen“ bewertet.

Aus den theoretischen Indikatoren werden zwei zusätzliche Indikatoren abgeleitet, welche die bisher ausgewählten Indikatoren ergänzen. Mit der „Ersatzteilpolitik des Herstellers“, wird bewertet, ob Hersteller Gruppen von Ersatzteilen für einzelnen Zielgruppen nicht verfügbar machen. Darüber hinaus wird die Dauer der Verfügbarkeit von Ersatzteilen in die optimierte Reparierbarkeitsmatrix aufgenommen.

Aufgrund der Ergebnisse der theoretischen Recherchen werden die folgenden Indikatoren ausgewählt:

- Verfügbarkeit von Ersatzteilen,
- Ersatzteilpolitik des Herstellers bzgl. des Modells,
- Dauer der Verfügbarkeit von Ersatzteilen,
- Lieferzeit für Ersatzteile,
- Kosten für Ersatzteile,
- Verfügbarkeit von Reparaturinformationen,
- Möglichkeit der Fehlerdiagnose,
- Verfügbarkeit aktualisierter Software / Firmware,
- Dauer der Verfügbarkeit aktualisierter Software / Firmware und
- Möglichkeit des Zurücksetzens auf Werkseinstellungen (für elektronische Geräte / Drucker).

Aus den Fallstudien wurden für die Indikatoren **Bewertungsklassen** abgeleitet, die die vorgefundenen Spannbreiten bei den untersuchten Geräten abbilden. Die optimierte Reparierbarkeitsmatrix mit ihren Bewertungsklassen und der Bepunktung ist in der nachfolgenden Tabelle 1 zusammengefasst.

Tabelle 1: Optimierte Reparierbarkeitsmatrix

Indikator	Bewertungsebene	Bewertungsklassen	Punkteskala
Demontagetiefe	Teile	A: Die Anzahl der benötigten Arbeitsschritte liegt bei ≤ als 70% des Mittelwerts B: Die Anzahl der benötigten Arbeitsschritte liegt bei > 70 bis ≤ 90% des Mittelwerts C: Die Anzahl der benötigten Arbeitsschritte liegt bei > 90 bis ≤ 110% des Mittelwerts D: Die Anzahl der benötigten Arbeitsschritte liegt bei > 110 bis ≤ 130% des Mittelwerts E: Die Anzahl der benötigten Arbeitsschritte liegt bei > 130% des Mittelwerts	A = 10 B = 7 C = 4 D = 1 E = 0
Befestigungsart	Teile	A: Wiederverwendbar B: Entfernbar C: Weder entfernbar noch wiederverwendbar	A = 10 B = 5 C = 0
Werkzeuge	Teile	A: Reparatur möglich ohne Werkzeuge, mit Standardwerkzeugen, die für Privatpersonen im Handel erhältlich sind oder mit mitgelieferten Werkzeugen B: Reparatur möglich mit spezifischem Werkzeug, das nicht mitgeliefert wird, aber von fachlich kompetenten Reparateur*innen erworben werden kann C: Reparatur möglich mit spezifischem Werkzeug, dass nicht mitgeliefert wird, aber von Vertragspartner*innen erworben werden kann D: Reparatur kann mit keinem Standardwerkzeug, mitgeliefertem Werkzeug oder erwerbbaren Werkzeug durchgeführt werden	A = 10 B = 7 C = 3 D = 0
Lösbarkeit der Seitenwände	Gerät	A: Vier Wände des Wäschetrockners lassen sich unabhängig von allen anderen Wänden abnehmen B: Drei Wände des Wäschetrockners lassen sich unabhängig von allen anderen Wänden abnehmen C: Zwei Wände des Wäschetrockners lassen sich unabhängig von allen anderen Wänden abnehmen D: Eine Wand des Wäschetrockners lässt sich unabhängig von allen anderen Wänden abnehmen	A = 10 B = 7 C = 4 D = 1

Indikator	Bewertungsebene	Bewertungsklassen	Punkteskala
Ersatzteilpolitik des Herstellers bzgl. des Modells	Gerät	Für Privatpersonen: A: Nicht sicherheitsrelevante Ersatzteile sowie sicherheitsrelevante Ersatzteile sind verfügbar B: Nur nicht sicherheitsrelevante Ersatzteile sind verfügbar C: Es sind keine Ersatzteile verfügbar Für fachlich kompetente Reparateur*innen: A: Nicht sicherheitsrelevante Ersatzteile sowie sicherheitsrelevante Ersatzteile sind verfügbar B: Nur nicht sicherheitsrelevante Ersatzteile sind verfügbar C: Es sind keine Ersatzteile verfügbar Für Vertragspartner*innen des Herstellers / den Hersteller: A: Nicht sicherheitsrelevante Ersatzteile sowie sicherheitsrelevante Ersatzteile sind verfügbar B: Nur nicht sicherheitsrelevante Ersatzteile sind verfügbar C: Es sind keine Ersatzteile verfügbar	A = 10 B = 5 C = 0 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0
Verfügbarkeit von Ersatzteilen	Teile	A: Das Ersatzteil ist für Privatpersonen, fachlich kompetente Reparateur*innen und Vertragspartner*innen / Hersteller verfügbar B: Das Ersatzteil ist für fachlich kompetente Reparateur*innen und Vertragspartner*innen / Hersteller verfügbar C: Das Ersatzteil ist nur für Vertragspartner*innen / Hersteller verfügbar D: Das Ersatzteil ist nicht verfügbar	A = 10 B = 7 C = 3 D = 0
Dauer der Verfügbarkeit von Ersatzteilen	Gerät	A: Langfristige Verfügbarkeit (≥ 10 Jahre bei Druckern und ≥ 15 Jahre bei Trocknern, nachdem die letzte Einheit des Modells auf den Markt gebracht wurde) B: Mittelfristige Verfügbarkeit (> 2 bis < 10 Jahre bei Druckern und > 2 bis < 15 Jahre bei Trocknern, nachdem die letzte Einheit des Modells auf den Markt gebracht wurde) C: Kurzfristige Verfügbarkeit oder keine Verfügbarkeit (≤ 2 Jahre bei Druckern sowie Trocknern, nachdem die letzte Einheit des Modells auf den Markt gebracht wurde)	A = 10 B = 5 C = 0
Lieferzeit für Ersatzteile	Teile	A: ≤ 4 Werktage B: 5-14 Werktage C: 15-21 Werktage D: ≥ 22 Werktage	A = 10 B = 7 C = 4 D = 1

Indikator	Bewertungsebene	Bewertungsklassen	Punkteskala
Kosten für Ersatzteile	Teile	Baugruppen: A: ≤ 20% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde B: > 20 bis < 50% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde C: ≥ 50% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde Unterbaugruppen: A: ≤ 10% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde B: > 10 bis < 20% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde C: ≥ 20% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde Bauteile: A: ≤ 5% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde B: > 5 bis < 10% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde C: ≥ 10% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde	A = 10 B = 5 C = 1 A = 10 B = 5 C = 1 A = 10 B = 5 C = 1
Verfügbarkeit von Informationen	Gerät	Für Privatpersonen: A: Es sind umfassende Informationen verfügbar B: Es sind grundlegende Informationen verfügbar C: Es sind keine Informationen verfügbar Für fachlich kompetente Reparateur*innen: A: Es sind umfassende Informationen verfügbar B: Es sind grundlegende Informationen verfügbar C: Es sind keine Informationen verfügbar Für Vertragspartner*innen des Herstellers / den Hersteller: A: Es sind umfassende Informationen verfügbar B: Es sind grundlegende Informationen	A = 10 B = 5 C = 0 A = 10 B = 5 C = 0 A = 10 B = 5

Indikator	Bewertungsebene	Bewertungsklassen	Punkteskala	
		verfügbar C: Es sind keine Informationen verfügbar	C =	0
Fehlerdiagnose	Gerät	A: Intuitive Schnittstelle: Fehler wird mit einem Signal kommuniziert, das ohne externe Begleitdokumentation verstanden wird B: Codierte Schnittstelle mit öffentlicher Referenztabelle: Fehler kann über Schnitt-stelle in Verbindung mit mitgelieferter oder öffentlich verfügbarer Begleitdokumentation (z. B. Fehlercodetabelle) ausgelesen werden. C: Öffentlich verfügbare Hardware- / Soft-wareschnittstelle: Es wird eine öffentlich verfügbare Hardware und / oder Software benötigt, um den Fehler auszulesen D: Proprietäre Schnittstelle: Um den Fehler auszulesen, wird eine proprietäre Hardware und / oder Software benötigt, die nicht mit dem Produkt mitgeliefert wird E: Mit keiner Schnittstellenart möglich	A = B = C = D = E =	10 7 4 1 0
Firmware	Gerät	A: Notwendige Aktualisierung der Firmware für ≥ 10 Jahre bei Druckern und ≥ 15 Jahre bei Trocknern, nachdem das letzte Modell auf den Markt gebracht wurde B: Notwendige Aktualisierung der Firmware > 2 bis < 10 Jahre bei Druckern und > 2 bis < 15 Jahre bei Trocknern, nachdem das letzte Modell auf den Markt gebracht wurde C: Notwendige Aktualisierung der Firmware ≤ 2 Jahre bei Druckern sowie bei Trocknern, nachdem das letzte Modell auf den Markt gebracht wurde	A = B = C =	10 5 0
Treiber (Nur für Drucker)	Gerät	A: Aktualisierung der Treiber für ≥ 10 Jahre für alle relevanten Betriebssysteme, nach-dem das letzte Modell auf den Markt ge-bracht wurde (Windows, macOS, Linux) B: Aktualisierung der Treiber für alle ursprünglich unterstützten Betriebssysteme für ≥ 10 Jahre nachdem das letzte Modell auf den Markt gebracht wurde C: Aktualisierung der Treiber für < 10 Jahre, nachdem das letzte Modell auf den Markt gebracht wurde	A = B = C =	10 5 0

Indikator	Bewertungsebene	Bewertungsklassen	Punkteskala
Zurücksetzen auf Werkseinstellungen und von Passwörtern (Nur für Drucker)	Gerät	A: Wiederherstellung der Werkseinstellungen und Zurücksetzen von Passwörtern ist mithilfe von im Gerät integrierter Funktion möglich B: Wiederherstellung der Werkseinstellungen und Zurücksetzen von Passwörtern ist mithilfe frei zugänglicher Hard- oder Software möglich C: Wiederherstellung der Werkseinstellungen und Zurücksetzen von Passwörtern ist nur Vertragspartnern des Herstellers / dem Hersteller möglich (Servicereset) D: Wiederherstellung der Werkseinstellungen und Zurücksetzen von Passwörtern ist nicht möglich	A = 10 B = 5 C = 1 D = 0

Quelle: Eigene Darstellung

Um die Anwendbarkeit der optimierten Reparierbarkeitsmatrix zu überprüfen, wurde diese an je zwei Laserdruckern und Wärmepumpentrocknern, die auch Teil der Fallstudien waren, getestet.

Um die Bewertungsklassen in einen **numerischen Wert für die Reparierbarkeit** zu überführen, wurde das Instrument einer Nutzwertanalyse gewählt. Mit diesem wurden zunächst für jeden Indikator ein Teilnutzen direkt abgelesen oder aus dem Mittel der Werte für die einzelnen prioritären Teile berechnet und diese dann zu Nutzwerten je Gerät zusammengefasst. Dabei wurden alle Indikatoren und Ersatzteile gleich gewichtet. Mit der eingesetzten Nutzwertanalyse ist es jederzeit möglich, den Indikatoren und Ersatzteilen ein unterschiedliches Gewicht zu geben.

Für die Überprüfung der Reparierbarkeitsmatrix wurden zwei relativ ähnliche Laserdrucker eines Herstellers ausgewählt. Es wurde erwartet, dass die Nutzwerte (als Werte für die Reparierbarkeit) dieser beiden Geräte eng beieinander liegen (Hypothese 1).

Um einen anderen Fall zu überprüfen, wurden zwei Wärmepumpentrockner unterschiedlicher Hersteller ausgewählt, die sich nach den Ergebnissen der Fallstudien in ihrer Reparaturfreundlichkeit stark unterscheiden. Für diese beiden Geräte wurde erwartet, dass der Unterschied zwischen den Nutzwerten größer sein würde als bei den Druckern (Hypothese 2). Weiterhin wurde erwartet, dass das Gerät, welches nach den Ergebnissen der Fallstudie reparaturfreundlicher ist (z. B. in Bezug auf geringe Demontagezeiten und eine großzügige Ersatzteilversorgung durch den Hersteller), einen höheren Nutzwert erzielen würde (Hypothese 3).

Durch die Anwendung der Reparierbarkeitsmatrix wurden alle drei Hypothesen bestätigt. Es wird daher angenommen, dass die Matrix dazu geeignet ist, die Reparierbarkeit von Geräten zu bewerten. Dabei werden die erwarteten Unterschiede zwischen den Geräten abgebildet.

Basierend auf den vorausgegangenen theoretischen und empirischen Erkenntnissen dieses Vorhabens werden abschließend **Maßnahmen zur Stärkung der Reparatur** (Kapitel 7) formuliert. Dazu wird zunächst eine **Bestandsaufnahme von Maßnahmen** (Kapitel 7.1) durchgeführt, inwiefern in zentralen politischen Programmen die Reparatur derzeit gefördert wird. Die Analyse verdeutlich, dass in mehreren politischen Programmen bereits auf die Notwendigkeit verwiesen wird, die Materialeffizienz durch eine Förderung der Reparatur durch diverse Maßnahmen zu erhöhen. Bisher fehlt es jedoch vor allem an einer Konkretisierung dieser Maßnahmen. Daher werden anschließend **Empfehlungen für Maßnahmen** (Kapitel 7.2) zur Förderung der Reparatur formuliert, die in produktpolitische Instrumente, wie z. B. dem Blauen Engel und der Ökodesign-Richtlinie integriert werden können. Die Anforderungen können dabei abhängig davon, ob es sich um Voraussetzungen für den Marktzutritt, oder um Label mit höheren Anforderungen handelt unterschiedlich anspruchsvoll ausfallen. Zu den empfohlenen Maßnahmen gehören unter anderem:

- Die Anzahl der benötigten **Arbeitsschritte** zur Demontage von Wäschetrocknern und Druckern muss bei ≤ 70% des Mittelwerts liegen.
- Die verwendeten **Befestigungen** müssen wiederverwendbar sein.
- Eine Reparatur muss möglich sein ohne **Werkzeuge**, mit Standardwerkzeugen, die für Privatpersonen im Handel erhältlich sind, mit mitgelieferten Werkzeugen.
- Die Verfügbarkeit von **Ersatzteilen** muss ≥ 10 Jahre bei Druckern und ≥ 15 Jahre bei Wäschetrocknern betragen, nachdem das letzte Modell auf den Markt gebracht wurde.
- Für Privatpersonen, fachlich kompetente Reparateur*innen und Vertragspartner*innen / Hersteller müssen nicht sicherheitsrelevante Ersatzteile sowie sicherheitsrelevante Ersatzteile verfügbar sein.
- **Ersatzteile** müssen innerhalb von 4 Werktagen geliefert werden.
- Hinsichtlich der **Ersatzteilpreise** dürfen Baugruppen maximal 20% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde, kosten. Unterbaugruppen dürfen maximal 10% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde, kosten. Bauteile dürfen maximal 5% der UVP des Produkts zu dem Zeitpunkt, zu dem das Gerät auf dem Markt platziert wurde, kosten.
- Umfassende **Informationen** wie Fehlercodetabellen, Explosionszeichnungen, Schaltpläne und Reparaturanleitungen müssen für Privatpersonen, fachlich kompetente Reparateur*innen und Vertragspartner*innen des Herstellers verfügbar sein. Zur **Fehlerdiagnose** muss der Fehler mit einem Signal kommuniziert werden, das ohne externe Begleitdokumente verstanden wird.
- Notwendige Aktualisierungen der **Firmware** müssen für ≥ 10 Jahre bei Druckern und ≥ 15 Jahre bei Trocknern verfügbar sein, nachdem das letzte Modell auf den Markt gebracht wurde.
- Bei Druckern müssen die Wiederherstellung der **Werkseinstellungen und das Zurücksetzen von Passwörtern** mithilfe von im Gerät integrierten Funktionen möglich sein.
- Bei Druckern müssen Aktualisierung der **Treiber** für alle relevanten Betriebssysteme (Windows, macOS, Linux) für ≥ 10 Jahre, nachdem das letzte Modell auf den Markt gebracht wurde, möglich sein.
- Bei Wäschetrocknern müssen sich die vier **Seitenwände** jeweils unabhängig von allen anderen Wänden abnehmen lassen.

Die in diesem Vorhaben erzielten Erkenntnisse zeigen weiteren **Forschungsbedarf** (Kapitel 8) auf, der abschließend benannt wird, wie zum Beispiel:

- Die Anwendbarkeit der erarbeiteten Reparaturmatrix sollte neben Wäschetrocknern und Druckern in weiteren Fallstudien überprüft werden.
- Für die für den Indikator „Arbeitsschritte“ ermittelten Bewertungsklassen sind Referenzwerte erforderlich, die über praktische Studien für weitere Produktgruppen ermittelt werden sollten.
- Hinsichtlich der prioritären Teile sollten in regelmäßigen Abständen Probeuntersuchungen durchgeführt werden, um zu ermitteln, welche Teile in den derzeit in den auf dem Markt befindlichen Geräten vorhanden sind.
- Neben den in diesem Vorhaben erarbeiteten technischen Aspekten, z. B. Befestigungsarten oder Werkzeuge, sollte analysiert werden, inwiefern ein Label für Reparierbarkeit die Kaufentscheidung beeinflusst und unter welchen Umständen Konsument*innen heutzutage defekte Geräte reparieren.

1 Introduction

Repair is a central measure of waste prevention and can therefore be located on the first level of the waste hierarchy anchored in the German Circular Economy Act (§6 KrWG). At the same time, it also plays a central role in the second level of the waste hierarchy, the so-called (preparation for) reuse (§3 Abs. 24 KrWG). Because instead of disposing products due to a defect during use, a repair extends the life of the product. On the one hand, this results in less waste, and on the other, it also saves resources that would otherwise be required for new production. Whether a defective product is repaired generally depends on numerous different factors. These include technical feasibility (e. g., availability of spare parts, non-destructive dismantling), economic profitability (e. g., repair time, cost of spare parts) and the provision of information (e. g., availability of repair instructions, transparency regarding repairability on the buyer side).

On the buyer's side, a lack of information on repairability leads to information asymmetry. Whether or not a product can be repaired cannot be used as a criterion for a conscious purchasing decision at this point in time, as the relevant information is not available to potential buyers. The need to create more transparency is therefore emphasized, including at the European level in the Waste Framework Directive (2018/851/EU), as well as on the national level in the German Circular Economy Act (§ 23 KrWG). A rating system for repairability could not only counteract this information asymmetry on the part of the purchaser, but also provide an incentive for manufacturing companies to produce repairable products.

On the manufacturer side, however, this also requires binding guidelines for a product design that fosters repair, including corresponding framework conditions. Such guidelines not only serve as an orientation for manufacturing companies on how products can be designed in a repair-friendly way, but also oblige them to adopt such a design in practice. This is necessary because product design often hinders repair - as the practical case studies in this project will show. The Ecodesign Directive is one instrument for setting binding requirements. In the Ecodesign Work Plan (2016-2019), the European Commission specifies, e. g., product-specific or horizontal requirements that can be applied across products, in the area of durability, repairability, upgradeability, dismountability and information dissemination.

Overall, there is a lack of a sound scientific basis about which factors individually and collectively favor repair and can thus be defined as a requirement for manufacturing companies and communicated to customers via appropriate labelling. This is where the planned project comes in. In the course of this project, factors favoring repair will be developed for complex products, above all electrical and electronic appliances, by combining theory and empirical findings.

1.1 Problem

In Germany alone, around 853,124 t of electrical waste was collected in 2018. The majority (around 772,934 t) came from private households (Löhle et al. 2020), which equals around 9.3 kg of e-waste per inhabitant. A study by Prakash et al. (2016) also shows that the average first-time useful life, i. e., the period of use by the first user of large household appliances that were replaced due to a defect, decreased by one year between 2004 and 2013 and is now 12.5 years. A defect is still the main cause of replacement (Prakash et al. 2016). Most critically, between 2004 and 2013, the proportion of appliances replaced due to a defect within less than 5 years increased from 3.5 to 8.3% of total replacement purchases. Analyses for other electrical and electronic appliances (e. g., washing machines, televisions, dishwashers, refrigerators) also confirmed the trend of decreasing first-time useful life. The reasons for the replacement of appliances are manifold. In general, functional, material, psychological and economic types of obsolescence interact and form highly complex patterns (Prakash et al. 2016).

The increasing amount of waste is problematic because electrical and electronic equipment are complex products. They consist of numerous different substances, components, and assemblies. The substances are incorporated into the appliances in small quantities, but high concentrations compared to their occurrence in natural deposits. Some of the processed substances are toxic and therefore pose a considerable risk to humans and to the environment if not handled properly. Others, however, have a high economic value. Instead of disposing the devices as waste, there therefore is great potential in returning the devices to the economy. This is also a compelling necessity to counteract the increasing consumption of resources and the burden on landfill options.

Repair is not only preferable over recycling in terms of ecological and economic aspects. Further advantages result from the technical limitations of recycling. Repair is preferable over recycling, especially in the case of electrical and electronic equipment since the recovery of many substances has been technically limited up to now. The appliances usually contain numerous metals with similar physical and chemical properties in high purity compared to natural deposits, but in very small quantities (Hagelücken 2006). This makes it difficult to recover the individual metal fractions by type and is only possible with a high input of energy. According to Hagelücken (2006), there is an inverse relationship between yield and purity of the recovered metals in recycling. This is also referred to as the “concentration dilemma” (Hagelücken 2006). This means that the higher the purity of the recovered metal fraction, the lower the yield since all non-pure fractions are completely separated. In addition, the economic viability of recycling is coming under pressure due to the increasing miniaturization of electrical and electronic devices (Hagelücken 2018).

Overall, there are numerous economic and ecological advantages associated with repair. Repair consumes significantly less energy and resources than required for new production because the functional units of the device are preserved and continue to be used (von Gries 2020, Gutowski et al. 2011). It can also have positive effects on the local level for the labor market and regional value creation, as additional jobs are created. According to a study by the European Commission (2018), different numbers of jobs are created depending on how waste products are handled. For 10,000 t of used products, one job can be created in waste combustion. Landfilling creates six jobs, although untreated landfilling of municipal waste has not been permitted in Germany since 2005. When products are recycled, 36 jobs can be created and when products are reprocessed and reused, up to 296 jobs are created.

However, the energy consumption of the repaired appliances in the subsequent use phase must be considered in a differentiated manner. Since new appliances are usually more energy-efficient than old ones, the mentioned energy savings resulting from refurbishment may be offset by higher energy consumption in the use phase compared to a corresponding new appliance. However, a study by Prakash et al. (2016), in which life cycle analyses were carried out for long-life and short-life washing machines, televisions and notebooks, shows that the long-life variant performed better than the short-life variant in all environmental categories examined, and thus extending the useful life through repair is beneficial.

Despite the political prioritization and the numerous advantages associated with repair, it still remains a niche phenomenon. Products are rarely repaired these days. According to Poppe (2014), it can be assumed that repair has even declined in recent years. There are several reasons for this. For example, there is a lack of repair-friendly product designs, framework conditions that favor repair and transparency for buyers regarding the repairability of a product. Last but not least, it is also a matter of price, because if a repair is in the same price range or is more expensive than buying a new product, the new purchase is often preferred for economic reasons.

1.2 Objectives

The overall objective of this project is to contribute to an increase in the repairability of products relevant to energy consumption and to implement the avoidance of waste in the circular economy. This is to be achieved by developing measures and standards that address repair. The focus is on technical feasibility, taking into account economic profitability. However, the focus is not on other social factors that influence repair in a fundamental way, such as the spread of repair practices (Krebs et al. 2018) or a repair culture (Jaeger-Erben 2017). They require a separate social and sociological analysis.

Firstly, within the framework of the project, horizontal requirements are defined through participation in several committees[2] (standardization mandate M/543) on a national and European level. Primarily, they concern the durability (Working Group 2) as well as the repairability, upgradeability and reusability (Working Group 3) of products. The standardization work is not included in this report. This work package was carried out by Dr. Brüning Engineering.

Secondly, a system for assessing the repairability of energy-related products is being developed, a so-called repairability matrix. On the one hand, it aims to provide interested buyers with additional information as a basis for making a conscious purchase decision. On the other hand, it simultaneously creates an incentive for manufacturing companies to already take repairability into account during product design. This work package is carried out by the Wuppertal Institute.

Thirdly and in parallel, the applicability of the repairability matrix will be practically tested in several case studies using printers and tumble dryers by dismantling selected appliances. The insights gained are incorporated into the standardization work and repairability matrix. This work package is carried out by Dr. Brüning Engineering.

Fourthly, based on the core results of this project, recommendations are formulated as to how these findings can be transferred into product policy instruments, especially within the framework of the Waste Avoidance Program (Abfallvermeidungsprogramm, AVP) and the Resource Efficiency Program (Resourceneffizienzprogramm, ProgRess) as well as the Ecodesign Directive. This work package is carried out by the Wuppertal Institute and Dr. Brüning Engineering.

Overall, this project develops requirements – theoretically grounded and empirically tested - to promote the material efficiency of energy-related products through a better repairability and thus a longer useful life. Thereby, it contributes to the implementation of a circular economy at the highest levels of the waste hierarchy, namely waste prevention.

[2] NA 172-00-14 GA, CENCENELEC TC10 WG2 (Durability), WG3 (Ability to repai, reuse and upgrade energy-related products), WG5 (Ability to remanufacture and method for determining the proportion of reused compoents in products)

2 Conceptual Framework

First, we define the term “repairability”. Then, the key components of a repairability assessment system are explained. According to a study by Cordella et al. (2019) for the Joint Research Centre (JRC), such a system is based on several pillars, including a) priority parts, b) indicators, c) rating classes, and d) a final label that communicates the rating to consumers.

2.1 Repairability

The term “repair” is defined according to DIN EN 45554, which states that repair is a “process of returning a faulty product to a condition where it can fulfil its intended use”. Hence, products are repairable if they can be restored to a functioning condition after a defect. On the one hand, this means that during a repair, components that are no longer functional, which include both parts and assemblies, are replaced by other components. These can be new, refurbished or used components. Thus, only the defective components are affected by a repair, so, for instance, no testing of other components takes place. On the other hand, a repair can also be carried out without replacing components, for example, if it is sufficient to reseal attachments that have become loose to restore the device to a functioning condition. According to DIN EN 45554, repair is, however, different from upgrade, because upgrade is a “process to enhance the functionality, performance, capacity or aesthetics of a product” (DIN EN 45554). Table 2 lists the respective definitions.

Table 2: Definitions of different refurbishment options

Term	DIN EN 45553 and DIN EN 45554
Repair	process of returning a faulty product to a condition where it can fulfil its intended use
Upgrade	process to enhance the functionality, performance, capacity or aesthetics of a product

Source: Own depiction acc. to DIN EN 45554

2.2 Priority Parts

Complex products, such as energy-related products, consist of numerous different components, therefore a selection of priority parts is essential. By focusing on these parts when assessing repairability, the complexity of the assessment process is reduced significantly. Priority parts are key parts of a product. However, different criteria exist to assess whether a part is of priority or not, such as: a) frequency with which a part becomes defective, b) functional importance of a part, c) economic value of the part, d) ecological importance of the part or e) steps required to disassemble the part. These criteria are usually not congruent. For example, a product part may have the smallest economic value but have the greatest environmental impact.

A stakeholder survey[3] conducted by the Joint Research Center by Corella et al. (2018a) found that over 80% of respondents considered the frequency of a part failing to be the most important aspect in determining priority parts. Accordingly, priority parts are defined as parts that typically fail during the normal use of a product. However, it must be noted that it only becomes apparent which parts fail frequently after a product has been on the market for a

[3] Following representatives took part in the survey: 15 industrial companies or industry organizations, 3 governmental authorities, 3 non-governmental organizations, 2 independent repair companies, 1 scientific institution, 1 commercial company. They are located in the following countries: 6 from Belgium, 4 from France, 3 from Germany, 2 each from Italy, Spain and the Netherlands, and 1 each from the Czech Republic, Denmark, Ireland, Sweden and the UK.

longer period, which makes it difficult to identify them in advance. Nevertheless, Table 3 shows an example of the priority parts of a kettle that usually fail frequently. They were identified in a study by the Waste and Resources Action Program (2014).

Table 3: Priority parts of a kettle based on failure frequency

Components	Error mode
Switch	Kettle does not switch off automatically, is too slow to switch off or does not switch on
Lid	Kettle lid does not stay closed or cannot be opened
Heating element	Heating elements of the kettle may fail prematurely or cause loud noises
Steampipe	Kettle is too slow to switch off caused by misallocation of steampipe
Water level window	Water leaks through water level window of kettle due to leak in seal

Source: Own depiction acc. to Waste and Resources Action Program (2014)

2.3 Indicators

The extent to which a product is repairable cannot be observed directly. Repairability is therefore a theoretical construct that must be operationalized with the help of measurable indicators. These indicators need to cover all dimensions that refer to the extent to which a product is repairable. Central indicators that influence the repairability of products can be divided, for example, into two categories: They either refer to the product design (e. g., non-destructive disassembly) or to the repair environment (e. g., repair instructions) and thus influence the repair indirectly or directly.

Generally, a distinction can be made between generic and specific indicators. Generic indicators are very general and can therefore be applied horizontally, across diverse product groups. Often, these indicators do not differ from indicators used to evaluate similar but different forms of repair, such as remanufacturing, upgrading and refurbishing. They can therefore also be used to evaluate such activities. For example, information on repair, without specifying it, falls under generic indicators. Specific indicators, on the other hand, concretize the generic indicators depending on the product group and can therefore only be used for specific product groups. An example of such an indicator is a manual with disassembly steps for replacing the heating element of a kettle.

2.4 Assessment systems

The assessment of repairability requires the existence of a rating system that classifies repairability. Basically, according to Cordella et al. (2018a), three assessment systems can be distinguished: a) qualitative assessments, b) semi-qualitative assessments and c) quantitative assessments. The assessment systems build on each other with increasing complexity. It depends on the desired intention, data availability and practical feasibility which system is used.

Qualitative assessments define dichotomous indicators that must be met to classify a product as repairable. They thus provide a checklist (e. g., priority parts can be easily dismantled), which is used to check individually whether the device meets or does not meet the requirement.

The checklist with the parameters of the qualitative assessment serves as a basis for **semi-quantitative assessments**. Instead of only checking whether the indicators apply or not, several alternatives are defined in each case for the individual indicators, which are then allocated to a graded rating (e. g., repair manual is freely accessible (1), repair manual is only freely accessible to contract value sites (0.5), repair manual is not freely accessible (0)). A numerical scale can be used for the individual indicators, as in the previous example, however alphabetical (e. g., A, B, C) or other (e. g., red, yellow, green) scales are also possible. Most approaches that currently exist and are used in practice follow this principle. Examples are the iFixit Scorecard or the ONR 192 102:2014. If some indicators are more relevant than others, these can also be weighted. The majority of stakeholders who participated in a survey and a meeting of the Joint Research Centre were in favor of weighting the individual indicators according to their importance. In addition to weighting, it is also possible to aggregate and normalize the individual indicators so that the final repairability score can result.

In a **quantitative assessment**, several individual indicators of one or more dimensions are combined to form an index that measures the degree of repairability of the product. It must be decided which dimensions are to be included in the index and how the dimensions are to be combined (e. g., additive, multiplicative). For example, the *ease of Disassembly Metric* (eDiM) calculates the ease of disassembly of products based on the time needed for disassembly and reassembly.

2.5 Possible labels

Regardless of the type of assessment system, a label is required that transparently communicates the obtained evaluation of the extent to which a product is repairable to potential buyers. There are various options for the design of such a label, which were also evaluated in the Joint Research Centre's stakeholder survey (2018) with the answers 0 for not suitable, 1 for not very suitable, 2 for moderately suitable and 3 for very suitable.

1. Binary (repairable - not repairable).

In a binary system, the degree of repairability cannot be communicated, however, buyers are more likely to be interested in whether a product is repairable - regardless of a percentage statement.

Stakeholder assessment: Ø = 1.1

2. Traffic light (green - orange - red)

A traffic light system is easy to understand for those interested in buying, also due to analogies to the energy efficiency label. However, it also does not allow sufficient differentiation between products, as only three categories can be distinguished.

Stakeholder assessment: Ø = 1

3. Stars (e. g., * - ** - *** - ****)

More than three stars allow for adequate differentiation between products and are easy to understand. Symbols other than stars that are directly related to repair, such as spanners, might be more intuitively understandable for those interested in buying.

Stakeholder assessment: Ø = 2

4. Alphabetical (e. g., A, C, D, E, F)

A label similar to the one for energy efficiency could either be very conclusive for prospective buyers or lead to confusion. Here, the positions of the stakeholders diverge widely.

Stakeholder assessment: Ø = 1.4

5. Numeric (e. g., 0-1, 1-10, 0-100)

A numerical label allows for adequate differentiation between products, but it could also turn out to be too detailed. For example, if the score differs between two products, even if only minimally, this does not necessarily correlate with a noticeable difference in practice.

Stakeholder assessment: Ø = 1.9

3 Analysis of existing approaches to assess repairability

The existing approaches can be divided into product-specific and generic approaches. Product-specific approaches refer either to particular products (e. g., washing machines, radios) or product groups (e. g., white goods, brown goods)[4], while generic approaches are applicable across product groups, i. e., horizontally. In general, the product-specific approaches have been around for several years, while the generic approaches have only recently been developed. The latter are also trying to develop an overarching evaluation system - and have taken place in parallel to this study in France, Benelux and at the European level. The existing approaches are evaluated regarding the extent to which they contain indicators that are central to the rating of repair, as well as which rating system is most practicable. The approaches are explained in detail below and finally discussed in summary.

3.1 Existing product-specific approaches

In practice, there are already various approaches to assess the repairability of products. The existing approaches vary between quantitative and qualitative assessment systems as well as combinations of these. They are explained in more detail below and finally, at least in the case of the semi-quantitative and quantitative approaches, compared with each other in tabular form based on relevant dimensions.

3.1.1 Existing qualitative approaches

The Blue Angel *(Blauer Engel)* and the *EU Ecolabel* are examples of qualitative approaches to assess the repairability of products, primarily addressing the environmental impact of products in general and only partially their repairability. These approaches therefore contain only individual indicators that refer to whether a product is repairable or not. If all criteria are met as a whole, the tested products receive the corresponding quality label.

3.1.1.1 Blue Angel

The eco-label Blue Angel *(Blauer Engel)* is a label of the German Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection. It distinguishes products and services that are more environmentally friendly than comparable products and services. So far, over 20,000 products and services of some 1,600 companies have been given the eco-label (Blauer Engel 2021). For each product group, criteria that have to be fulfilled in order to receive the eco-label are developed and updated at regular intervals. Among the criteria for individual products, there are some requirements for their repairability.

Some requirements[5] directly or indirectly related to repair were identified through a sample review of the award criteria, as well as some relevant definitions of key terms, such as spare part and universal tool. A non-exhaustive selection of the identified criteria, which occur for some but not all products, is explained in the following and provided with relevant product examples:

The supply of **spare parts** must be ensured by the manufacturer for a defined period of time after production has ceased, depending on the product group and measured by the average product life span. Spare parts are understood to be functional parts (DE-UZ 147), which are defined as those parts that can typically fail during the normal use of a product (DE-UZ 136, DE-UZ 188, DE-UZ 131). Other parts that regularly outlast the life of the product are not considered

[4] White goods include kitchen appliances, such as refrigerators and washing machines, while consumer electronics appliances, such as televisions and computers, belong to brown goods.

[5] The requirements were taken from the respective product sheets (as of 2018).

spare parts (DE-UZ 136, DE-UZ 188). Spare parts must be offered at a reasonable price by the manufacturing company or by a third party (DE-UZ 78). For coffee machines, for example, spare parts for fully automatic machines and portafilters must be available for at least 10 years and for other coffee machines for at least 5 years after the last product was placed on the market.

Product **design requirements** primarily provide a recycling-friendly design, which means that appliances are designed in such a way that the highest possible recycling rate can be realized. Nevertheless, the criteria can also be applied to repair, as they address the disassembly process as the following examples illustrate:

- Devices must be designed in such a way that functional units can be easily separated from each other (DE-UZ 78, DE-UZ 196), e. g., in the case of computers into casing parts, chassis, batteries, screen units and printed circuit boards, in order to recycle them (DE-UZ 78). Moreover, it must be possible to remove batteries and electrical assemblies from the encasing.
- For easy and quick disassembly, fasteners must also be detachable with conventional tools and connecting elements must be easily accessible (DE-UZ 136, DE-UZ 174, DE-UZ 188). Universal tools necessary for disassembly are understood to be commonly used tools available on the market (DE-UZ 78, DE-UZ 205, DE-UZ 196).
- It must be possible for the dismantling to be carried out either manually by a specialized company and by a single person (DE-UZ 196, DE-UZ 78, DE-UZ 78c).
- Disassembly instructions must be available, even if only for handlers with the aim of promoting material recovery (DE-UZ 136, DE-UZ 188) or the product documentation must contain information on this (DE-UZ 183).

In addition to the criteria for spare parts supply and dismantling-friendly product design, the requirements for recycling-friendly dismantling (12 requirements) and the reusability of components and assemblies (5 requirements) for printers should be emphasized in the form of must-meet- and should-meet-criteria because they are relatively specific (DE-UZ 205). For example, remanufactured assemblies or components may be used for printers and half of the components of a device must be identical in construction to other devices of the same manufacturing company.

3.1.1.2 EU Ecolabel

The *EU Ecolabel* is an environmental label by the member states of the European Union and some European non-EU states, which was developed as a voluntary label in 1992. The label[6] identifies products and, since 2002, also services with a lower environmental impact than comparable products and services to make it easier for prospective buyers to make environmentally conscious purchasing decisions. To date, around 40,000 products in various categories carry the EU Ecolabel.

The label can be applied for by manufacturing, importing, distributing or service companies. The application is made in the member state where the product was manufactured, first marketed, or imported from a third country. The competent organization checks the application against predefined criteria and, if all requirements are met, awards a contract for the use of the label. This is valid for the period of the respective award criteria. The criteria are renewed every three

[6] The information is based on the EU Ecolabel website (as of October 2018).

to five years to adapt to innovations and to maintain the quality standard. Existing contracts must then be adjusted to the new standards.

Applicants are given a list of requirements that they must demonstrate through declarations and test reports. The criteria are developed by experts together with key stakeholders. The most significant environmental impacts over the entire product life cycle are considered. As a result, the criteria focus on the specific characteristics of each product type and are not universally applicable to all products.

There are some criteria that address the use of **recycled materials** or the potential **recyclability** of the product or packaging. Criteria that aim at disassembly for easier recyclability can also be applicable for easier repairability, analogous to the Blue Angel. Although the EU Ecolabel currently comprises 32 product categories, only the criteria of two products relate directly to repairability:

- Computers and tablets (EU 2016/1371) shall be designed in a way that they are easy to repair, update and recycle. This means that the product is accompanied by clear instructions in form of a manual to allow basic repairs. Spare parts must be available for at least five years from the end of production of the notebook. In addition, the manufacturing company must allow the disassembly of devices within the computer and tablet and grant the replacement of memory and graphic cards. (EU Ecolabel 2018b, EU Ecolabel 2018c)
- For televisions (EU 2009/300/EC), the required criteria stipulate that they are easy to repair and recycle. The consumer is provided with information on who is qualified to repair the television. The label promises that the TV will function for two years, and spare parts must be available for seven years from the end of production. In addition, a take-back guarantee after use is mandatory to encourage recycling. As with computers and tablets, easy disassembly should be guaranteed. (EU Ecolabel 2018d)

3.1.2 Existing semi-quantitative approaches

In contrast to qualitative approaches, the primary objective of semi-quantitative approaches is to specifically classify repairability rather than overall environmental performance, taking into account repair aspects. Semi-quantitative approaches include ONR 192102:2014, the iFixit Scoring System, the Repairability Indicator and repairability.org. They are first explained individually and then compared in tabular form.

3.1.2.1 Austrian Standardization Rule (ONR 192102:2014)

ONR 192102:2014 is an Austrian quality mark for durable, repair-friendly designed electrical and electronic devices. It is not a standard, but a rule that can be developed further into a standard if required. The ONR only addresses brown goods and white goods. To assess the repairability of the appliances, 40 criteria are specified for white goods and 53 criteria for brown goods, which are almost identical. These criteria are either should-meet-criteria, for which a certain number of points should be achieved, or must-meet-criteria, which must be fulfilled. If the label comprised only mandatory criteria, it would be a qualitative approach, but since it also includes should-meet-criteria for which a certain score can be achieved, it belongs to the semi-quantitative approaches.

The **must-meet-criteria** cover essential requirements to ensure the durability and repairability of the equipment. These include, for example, that the devices achieve a defined minimum service life, a list of suppliers for spare parts and those spare parts themselves are available over a certain period. If a must-meet-criteria is not met, the tested appliance cannot be certified.

On the other hand, for **should-meet-criteria** a certain minimum number of points between a maximum of 5 and a maximum of 10 points must be achieved, whereby the assessment is made by the tester. For example, if the essential parts of the device can be dismantled without special tools, this can be assessed with a maximum of 10 points. The points reached for the individual should-meet-criteria are then added up and converted into quality levels between 5 and 10 using a conversion table. Based on this, the final evaluation of repairability and durability is made on a graduated scale (good, very good, excellent) and is noted on the quality label. Table 4 shows the conversion table of the score for quality levels and rating.

Table 4: Conversion table for quality levels and scoring of ONR 192102:2014

Reached score	Quality level	Rating
45 to 69	5	Good
70 to 94	6	Good
95 to 119	7	Very good
120 to 144	8	Very good
145 to 175	9	Excellent
175 to 205	10	Excellent

Source: Own depiction acc. to ONR 192102:2014

3.1.2.2 iFixit Scoring System

iFixit is a worldwide community of people who support each other to repair things with a special focus on electrical and electronic devices. The different activities of iFixit are pooled on an interactive platform.[7]

iFixit tests the repairability of tablets, smartphones, and laptops on a regular basis. For analysis, the devices are disassembled by technical experts and evaluated with a so-called scorecard[8]. The scorecard contains several criteria. It includes, among others, the difficulty of opening the device, the fastening elements used inside and the complexity of replacing main components. Additional points are given for upgradeability, use of common screws and modularity of components. For each criterion, a unit can receive either 5 or 10 points.

A maximum of 100 points can be reached in total. The number of points reached is divided by 10 to give the final score on a scale between 0 (red) and 10 (green), with unrepairable units receiving a 0 and very easily repairable units a 10. Primarily, the rating serves to inform consumers. It is therefore available online and free of charge.

In addition, users can post and access repair instructions via the iFixit platform, in which the degree of difficulty, time required, the necessary tools and the individual steps of the repair are systematically described. The necessary tools and suitable spare parts can also be purchased directly via the platform. In this way, 67,453 manuals have been made available free of charge so far and 169,935 instructions for 31,448 devices have been created (as of September 2020).

[7] Find the website of iFixit at https://www.ifixit.com/

[8] The information is based on iFixit's website and a presentation by them (as of September 2020).

3.1.2.3 Repairability.org

The so-called *Design for Repairability* is an interactive tool developed by iFixit as part of a European Union project to develop a methodology for repairability. The following describes a preliminary interim status of this work, which was temporarily available online at repairability.org.

The tool defines criteria for a repairability-friendly design of brown goods. These must be considered in product design if consumers should be able to repair a product by themselves. The tool includes a total of 20 criteria, which are rated on a scale of 0 to 2 - with 0 being critical, 1 being mediocre and 2 being good performance. A maximum of 40 points can be reached in total, with the number of points reached being divided by 4, so that the final score, as with iFixit's methodology, is on a scale between 0 and 10.

3.1.2.4 Repairability Indicator

The *Repairability Indicator* for electrical and electronic equipment developed by Flipsen et al. (2016) builds on iFixit's scorecard. In an experiment, Flipsen et al. (2016) tested whether the iFixit scorecards could also be used by inexperienced users. They were first shown a repair video of a smartphone and then asked to rate the repairability of the smartphone themselves. For the smartphone shown, iFixit awarded a score of 7, the participants an average score of 5.85, but with an unusually wide variance between 2.5 and 9.5.

Flipsen et al. (2016) then developed a new indicator specifically for self-repair and tested it with students. This resulted in a list of 20 repairability criteria, each ranked on a scale of 0 to 2, where 0 is rated as negative, 1 as neutral and 2 as positive. However, a final scale for evaluating the repair is not provided. The criteria correspond to those of repairability.org, but different actors and products are addressed. While iFixit's system was developed for experts, this approach reviews it for self-repairs, and that of repairability.org is aimed at designers.

3.1.2.5 Comparison of the approaches

The semi-quantitative approaches have several things in common, especially the last three approaches mentioned are substantially interwoven. However, they also differ in several dimensions, for example regarding the person by whom the repair is carried out or the total number of indicators that need to be checked. Table 5 compares the semi-quantitative approaches.

Table 5: Comparison of the semi-quantitative approaches for assessing repairability

Approach	Repairer	Product category	Number of indicators	Indicator characteristics	Final Rating
ONR	Repair company	Brown Goods	53, thereof 22 must-meet-criteria	Should-meet-criteria: max. 5	Excellent Very good Good
		White Goods	40, thereof 17 must-meet-criteria	Should-meet-criteria: max. 10	
iFixit	Technician	Tablets Smartphones Laptops	15	5 or 10 Points	0 to 10
Repairability.org	Designer	Brown Goods	20	Critical: 0 Mediocre: 1 Good: 2	0 to 10

Approach	Repairer	Product category	Number of indicators	Indicator characteristics	Final Rating
Repairability Indicator	Self-repair	Electrical and electronic equipment	20	Negative: 0 Neutral: 1 Positive: 2	- (No final rating)

Source: Own depiction

3.1.3 Existing quantitative approaches

The existing quantitative approaches mainly address the time needed for disassembly. Disassembly is an essential part of the repair process, partly because many other indicators are involved, such as the type of fasteners or the internal assembly of the components. Two different time periods can be considered and calculated using different methods, which are listed in Table 6. The first is the time required for the disassembly of each individual attachment (U-effort) and the second is the time needed to carry out the various dismantling procedures (Philips EEC, Desai & Mital, Kroll). The calculations were originally developed for standardized production processes, which makes it difficult to transfer them to the usually very individually organized repair environment. However, disassembly time is only one of several quantitative approaches to assess the repairability of a product.

Table 6: Overview of quantitative methods for calculating the time for dismantling

Considered period of time	Calculation method
Time required for the disassembly of each individual attachment	U-effort
Time needed to carry out the various dismantling procedures	Philips ECC, Desai & Mital, Kroll

Source: Own depiction acc. to Vanegas et al. (2016)

3.1.3.1 U-effort

The U-effort method focuses on determining the time required for disconnecting fasteners. First, the so-called Unfastening Force Index (UFI) must be determined using Formula 1 to be able to calculate the disassembly time per connector ($T_{U\text{-effort}}$) (Formula 2) in the following step. The time given refers to an average worker and depends on the specific characteristics of the fasteners, such as size and shape.

$$\mathbf{UFI_i} = \mathbf{\Psi_i} + \ \text{ß}_\mathbf{a} * \mathbf{A_i} + \ \text{ß}_\mathbf{b} * \mathbf{B_i} + \text{ß}_\mathbf{c} * \mathbf{C_i} + \text{ß}_\mathbf{d} * \mathbf{D_i} \ [1]$$

$$\mathbf{T_{U-effort}} = \mathbf{5} + \mathbf{0.04} * (\mathbf{UFI})^\mathbf{2} \ [2]$$

$\mathbf{\Psi_i}$	Minimum detaching force required, which can be taken from **Table 7** for the various fastener types
i	Number of the fastener
Ai, Bi, Ci, Di	Various causal attributes, e. g., for a screw the causal attributes include head shape, length, diameter and use of washers
βa, βb, βc, βd	Weighting of the attributes

Table 7: Minimum force required to release various connectors after U-effort

Connecting element	$\mathbf{\Psi_i}$
Bolt	30
Snap lock (*Cantilever*)	20
Snap lock (*Cylindrical*)	36
Nail	15
Screw and nut	40
Clip release	10
Locking / retaining rings	25
Screw	25
Clamp	20
Velcro / zip fastener	0

Source: Own depiction acc. to Vanegas et al. (2016)

However, studies by Duflou et al. (2008) and Peeters et al. (2015) show that less than 50% of the total disassembly time is needed to disconnect compounds (Vanegas et al. 2016). Thus, the disassembly time calculated with this method is not valid, as the times for other necessary disassembly operations, such as identifying and disconnecting fasteners as well as changing tools, are not considered. Furthermore, the flexibility of the method is limited as the specific characteristics must be determined for each new type of fastener (Vanegas et al. 2016).

3.1.3.2 Philips ECC

The Philips ECC method described by Boks et al. (1996) uses a database to calculate the disassembly time, which contains standardized times for fastener disconnection and common disassembly tasks, such as the time required for a tool change.

Table 8 shows examples of the disconnection time required for different fasteners. The times contained in the database were determined with the help of real time measurements during real disassembly work, or by analyzing videos. After first defining the disassembly procedure and the type of fasteners, the model then automatically determines the disassembly times, the required handling, the tool operation, and the disconnection time by using the times stored in the database, which are average values for specific product categories (Vanegas et al. 2016).

Table 8: Disconnection time required for various fasteners according to Philips ECC

Fastener type	Time [s]
Screw	6.5
Tight screw	10.5
Click	3.5
Tight click	7.5
Cable / wire connection	2.0
Change of screwdriver	4.0
Screw and nut	11.5

Source: Own depiction acc. to Vanegas et al. (2016)

3.1.3.3 Desai & Mital

The *disassembly design method* developed by Desai and Mital (2003) calculates disassembly time by considering five factors: force, material handling, tool use, accessibility of components and connecting elements, as well as tool positioning (Vanegas et al. 2016). To perform the analysis, different disassembly tasks are scored according to their difficulty, where a basic disassembly task involves removing an easy-to-grip object by hand without requiring much force from a trained worker. For this basic task, a score of 73 Time Measurement Units (TMUs) is given, which is equivalent to approximately 2 seconds. The times for other common disassembly tasks are based on detailed time studies (Vanegas et al. 2016). Preparatory tasks, such as grabbing, picking up, and resetting tools, are not considered in this method, so the estimate of disassembly time can be considered incomplete (Vanegas et al. 2016).

3.1.3.4 Kroll

The Kroll method calculates the required disassembly time based on manual disassembly trials on computers, keyboards, monitors and printers (Kroll/Hanft 1998). A distinction is made between a basic time for sixteen basic disassembly tasks, which are shown in Table 9, and four difficulty categories (Vanegas et al. 2016). These difficulty categories include accessibility, positioning, force and other, with the last category considering non-standard aspects that also affect disassembly time (Vanegas et al. 2016). Based on this, the time of disassembly of a product can be calculated using Formula 3.

Table 9: Disassembly tasks by Kroll

1. screw off, unscrew	2. twist, turn	3. clamp / break open, pry up	4. cut, shorten
5. remove, take out	6. turn over	7. deform	8. push / pull
9. hold, grip	10. saw	11. drill	12. hammer, knock
13. peel, strip	14. clean, refine	15. grind, mill	16. test, examine, check, inspect

Source: Own depiction acc. to Vanegas et al. (2016) based on Kroll/Hanft (1998)

$$T_{Kroll} = (D - 5 * R) * 1.04 + M * 0.9 \quad [3]$$

D Sum of difficulty scores for the four categories and the basic time

R Number of task repetitions

M Number of tool uses

3.1.3.5 eDiM

In addition to these methods, there is the *ease of Disassembly Metric* (eDiM), which gives a quantitative indication of the time and thus the difficulty of disassembly and reassembly of a product. Originally, eDiM was developed for standardized work procedures in production. Therefore, it must be examined whether it is useful to apply it to repair, which is usually less standardized.

This method considers both times, i. e., the time for disassembly of the joints and the time for execution. The tasks required for disassembly and reassembly of a particular product are listed and each of them is assigned reference time values representing the effort required to perform this operation. The reference time values are used from MOST (Maynard Operation Sequence Technique). MOST was developed by the company H.B. Maynard (today: Accenture) in order to have standardized times available for the execution of work steps, e. g., assembly times of different products. The times measured with MOST represent the performance of an average skilled worker working under adequate supervision, under average working conditions and at a normal pace.

The determination of the disassembly time according to eDiM is done with the help of a calculation sheet shown in Table 10. It is divided into two main components, which are filled in successively. They are described below.

Table 10: Calculation sheet according to eDIM

1	2	3	4	5	6	7	8	9	10	11	12	13
Disassembly order of the components	Disassembly order of the fasteners	Number of fasteners	Number of product handlings	Identifiability (0,1)	Type of tool	Tool change	Identification	Handling	Positioning	Disassembly	Dismantling / Removal	eDiM
1...												
2...												
...												
N												
|------------------Provision------------------|						|--------------Calculation------------|						

Source: Own depiction

In the first six columns (1 to 6), the basic information of the product is entered. Six parameters are taken into account. They describe the individual steps of disassembly and include:

1. **Disassembly order of the components**: This parameter lists the components to be disassembled in the appropriate order.
2. **Disassembly order of the fasteners:** For each component, all types of fasteners are listed. A component can have several and/or different types of attachment.
3. **Number of fasteners:** For each type of fastener, the number is determined.
4. **Number of product handles:** Number of handles required for each activity (e. g., disconnecting the fasteners).
5. **Identifiability:** Evaluation of the ability to identify the fasteners. A distinction is made between visible and concealed.
6. **Type of tool:** Indication of the tool used to loosen the different fasteners.

Based on this, the estimated standard times are entered in the following seven columns (7 to 13), based on the information previously entered in the first six columns and the MOST reference time values:

7. **Tool change:** Time needed to change the tools (reference to column 6).
8. **Identification:** Time needed to identify the fasteners, depending on the degree of concealment (reference to column 5).
9. **Handles:** Time taken for the previously entered required handles (reference to column 4).
10. **Positioning:** Time needed for the different positioning of the product. Results from multiplying the number of fasteners entered in column 3 by the standard times for the necessary tool or product positioning.
11. **Disconnection:** Time required for disconnecting individual attachments. Results from multiplying the number of fasteners entered in column 3 by the standard times for disconnecting the corresponding attachment.
12. **Disassembly:** Time taken to separate individual components.
13. **eDiM:** The parameter in column 13 indicates the total time required. The sum of all times in the same row gives the time needed for the individual steps. The sum of all the rows in column 13 gives the time needed for disassembly up to step N. N is the number of steps required until either the defective element is removed, or the product is completely dismantled.

3.1.3.6 Comparison of the approaches

The four methods, U-effort, Philips ECC, Desai & Mital and Kroll, used to calculate the disassembly time will be depicted in Table 11 according to Vangeas et al. (2016), complemented by the eDiM method. They are compared regarding their main objective, the calculation approach, and their key limitations.

To sum it up, it can be stated, that quantitative approaches are associated with a profound higher complexity than qualitative and semi-quantitative approaches, as shown with the explanation of the calculation of disassembly time. Therefore, the Joint Research Centre has also refrained from taking a quantitative approach to assessing the repairability of products in its current study.

Table 11: Comparison of the quantitative methods for calculating the time for disassembly and reassembly

Approaches	Main objective	Calculation approach	Key limitations
U-effort	Support concept for disassembly	Based on the characteristics of plug connectors	Exclusively considering the time for disconnecting the attachments; not precise

Approaches	Main objective	Calculation approach	Key limitations
			enough; high modelling effort for new plug connectors
Philips ECC	Calculation of EoL costs	Database with current dismantling times	Limited to certain product categories; expected to have low accuracy when widely applied
Desai & Mital	Support concept for disassembly	Factors that influence ease of disassembly are evaluated with the MTM time system	Preparatory work not included
Kroll	Support concept for recycling	Base time for fasteners and difficulty values based on MOST	Overly detailed for product policy; the assignment of difficulty levels can be seen as subjective
eDiM	Quantitative statement about the dismountability of products	Base time for fasteners, their number, difficulty and further disassembly work based on MOST	Considerable computing effort, unless software is developed

Source: Own depiction based on Vanegas et al. (2016)

3.2 Existing generic approaches

In addition to the product-specific approaches, current work, in parallel with this project, also seeks to develop generic repair indicators. These include a study in the context of Benelux by Bracquené et al. (2018), a study by the Joint Research Centre on behalf of the European Commission by Cordella et al. (2018b) and the repair indicator developed in France (French Repair Index). They offer a first helpful orientation, but they are mostly theoretical works whose applicability has either not been tested in practice (French Repair Index, Joint Research Centre study) or only to a limited extent (Benelux study). These approaches are explained in detail below.

3.2.1 French Repair Index

In France, a labelling obligation came into force in 2021, which obliges manufacturing companies to indicate via a label to what extent an appliance can be repaired in the event of a defect. The repair index is a measure of the practical implementation of the so-called anti-waste law for a circular economy (2018). It aims to ensure that around 60% of electrical and electronic equipment is repaired in France in the next five years, compared to around 40% at present (Ministry for the Ecological and Solidarity Transition 2020).

The repair index[9] (as of September 2020) is intended to be a generic index but has so far been adapted and applied to five appliances on a product-specific basis. These include smartphones, washing machines, laptops, televisions, and lawnmowers. In perspective, with these practical findings, the repairability index will be converted into a durability index in 2024.

[9] All information is based on a presentation of the French environmental authority (2019) and a factsheet of the Round Table Repair (2020), which is why there may still be changes until the introduction.

The score must be directly visible on the product or packaging at point of sale. A maximum of 10 points can be reached. The index consists of the following five criteria with sub-criteria, which are explained below:

- Information

  Specified information (e. g., exploded drawing, electrical panels, user manuals, fault codes, tools) must be kept for a certain period of time (<3 years, 3 years, between 3 and 6 years, between 6 and 9 years) after the last device has been placed on the market. In addition, it is relevant for whom (authorized workshop, independent workshop, private person) this information is available.

- Disassembly

  Disassembly includes on the one hand the effort for disassembly as well as for reassembly of parts (number of work steps) and on the other hand the tools required to do so (without tools, standard tools, special tools, disassembly not possible).

- Spare parts

  The availability of spare parts for certain actors (authorized workshop, independent workshop, private person) is relevant, as well as the duration of availability after the market launch of the last device (3 years, 6 years, 9 years) and the delivery time (<2 working days, between 2 and 5 working days, between 5 and 15 working days, >15 working days).

- Spare part price

  The price of the most expensive spare part in relation to the market price of the product at the time of calculation. The higher the percentage, the worse the product performs.

- Product-specific criterion that differs depending on product group

3.2.2 Standardization work of the Technical Committee CEN/CLC/JTC 10

In parallel to this project, the Technical Committee developed the European standard "General methods for the assessment of the ability to repair, reuse and upgrade energy-related products" (EN 45554). For information purposes, Annex A of this standard contains an assessment procedure that can be used not only for repair but also for reuse and upgrade. The system is listed in Table 12.

The assessment procedure contains a total of 13 indicators. For the specific assessment of a product or a product group, those indicators have to be selected that are applicable, appropriate and relevant. This must be done in a product-specific assessment procedure.

Assessment classes are given in an alphabetical system, whereby the amount of assessment classes differs from indicator to indicator. Each assessment class should be assigned a numerical value that is used in place of the letters, whereby individual values can also be weighted: The higher the value, the greater the repairability of a product.

No system is prescribed for the final rating. It can be given alphabetically, numerically or in any other way.

Table 12: Summarized rating system according to DIN EN 45554

Indicator	Classification
Fasteners	A: Reusable B: Removable C: Neither removable nor reusable
Tools	A: Feasible: - without the use of any tools, or - using a tool or set of tools that is supplied with the product, or - using only basic tools as listed in Table A.3 of the standard DIN EN 45554 B: Feasible with product group specific tools C: Feasible with other commercially available tools D: Feasible with proprietary tools E: Not feasible with any existing tool
Working environment	A: Use environment B: Workshop environment C: Production-equivalent environment
Skill level	A: Layman B: Generalist C: Expert D: Manufacturer or authorized expert E: Not feasible with any existing skill
Diagnostic support and interfaces	A: Intuitive interface B: Coded interface with public reference table C: Publicly available hardware / software interface D: Proprietary interface E: Not possible with any type of interface
Availability of spare parts by target group	A: Publicly available B: Available to independent repair service providers C: Available to manufacturer-authorized repair service providers D: Available to the manufacturer only E: No spare parts available
Availability of spare parts by spare part interfaces	A: Standard part B: Proprietary part with standard interface C: Proprietary part with non-standard interface
Availability of spare parts by duration of availability	A: Long-term availability B: Mid-term availability C: Short-term availability D: No information on duration of availability
Types and availability of information by comprehensiveness	A: Comprehensive information available B: Basic information available C: No information available
Types and availability of information by target groups	A: Publicly available B: Available for independent repair service providers C: Available to manufacturer-authorized repair service providers

Indicator	Classification
	D: Available to the manufacturer only
Return models	A: Comprehensive return model existing B: Basic return model existing C: No return model
Data transfer and deletion	A: Built-in B: On request C: Not available
Password and factory reset for reuse	A: Integrated reset B: External reset C: Service reset D: No reset

Source: Own depiction based on DIN EN 45554

3.2.3 Study in the Benelux context by Bracquené et al. (2018)

A study in the context of Benelux by Bracquené et al. (2018) develops generic repair indicators based on the existing approaches. They divide the repair process into several operational steps (horizontal): a) product identification, b) fault diagnosis, c) disassembly and reassembly, d) replacement of spare parts, e) restoration of operating condition. They assign indicators to the individual work steps, which are divided into three groups (vertical): a) information (e. g., disassembly instructions), b) product design (e. g., effort required for disassembly), c) service of the manufacturing company (e. g., availability of spare parts). By combining the work steps with the indicators, a matrix for assessing repairability is created. Table 13 lists the individual indicators.

Table 13: Repair indicators classified by indicator type according to Bracquené et al. (2018)

Information availability requirements	Product design requirements	Service availability requirements
Maintenance instructions	Durability	Spare parts availability
Fault identification	Test software, test mode	Warranty service
Repair instructions	Upgradeability	Return system
Spare parts information	Priority parts, key components	
	Disassembly difficulty (tools, joints, force, standardization, modularity, accessibility, time, skills)	

Source: Own depiction acc. to Bracquené et al. (2018)

The indicators are weighted differently. A total of 164 points can be scored. For individual indicators, a maximum of 2 (e. g., difficulty of reset), 5 (e. g., technical support), 12 (e. g., information for 3D printing), 15 (e. g., accessibility and robustness of product design) or 20 (e. g., modular design) points can be awarded.

The repair matrix was tested using a washing machine and a vacuum cleaner from the perspective of a private person and that of a professional repair company. More detailed information on the appliance models is not given. The washing machine reached a total of 127 points and the hoover 111 points. For both appliances, it was found that the score of individual indicators is higher for a professional repairer than for a private person, i. e., a repair can be carried out more easily by a repairer. This is partly due to the lack of availability of information for private individuals and the better availability of spare parts for repairers. They conclude with a recommendation to apply the indicators to other products to test their applicability.

3.2.4 Joint Research Centre study by Cordella et al. (2019)

On behalf of the European Commission, the Joint Research Centre commissioned Cordella et al. (2019) to first develop a horizontal evaluation system for repairability and then adapt it to specific products such as laptops, vacuum cleaners and washing machines. The product-specific adaptation was exclusively theoretical.

The approach is mainly based on the findings of the CEN-CENELEC-JTC10 during the development of the EN 45554 standard. However, the indicators and assessment classes deviate slightly in some cases. The system consists of 12 parameters in total. They refer either to priority parts or to the whole product, as shown in Table 14. The parameters are, on the one hand, must-meet-criteria that assess whether a product is repairable and, on the other hand, should-meet-criteria that classify to what extent the product is repairable. The "must-meet-criteria" must be fulfilled in a first step to evaluate the product by the "should-meet-criteria" in a second step.

Table 14: Assessment levels of the repairability indicators of the Joint Research Center study

Assessment level	Indicator
Priority part	Disassembly depth and sequence (1), fasteners (2), tools (3), disassembly time (4), spare parts (7), safety (9), knowledge and working environment (9)
Entire Product	Diagnostic support and user interface (5), type and availability of information (6), software and firmware (8), data transfer and deletion (10), password reset and factory reset (11), warranty (12)

Source: Own depiction acc. to Cordella et al. (2018b)

The criteria are applicable to test both repairability and upgradeability. They address either the product design (1-4) or the repair process (5-11), so that different facets of repairability are included. Economic indicators, such as the price of spare parts, are not considered.

3.3 Derivation of potential repairability indicators from existing approaches

Based on the existing approaches for assessing repairability, an overview of the contained indicators is compiled. They provide an initial orientation for potential repairability indicators. The indicators of the existing approaches are classified into thematic dimensions so that indicators with similar content are covered by the same dimension. However, indicators that follow a different logic, such as "modular design", or product-specific design requirements, such as "easily accessible measuring points at the edge of the board", are not taken into account.

The result, as shown in Table 15, is an overview of 37 indicators in 11 dimensions that relate either to the product or a component of the product. Furthermore, the compiled overview is compared to the indicators of DIN EN 45554, as their practical applicability is to be checked in the further course of the project.

The individual indicators must not be seen as isolated but are rather complexly interwoven. Disassembly time can be reduced, for example, by having detailed information on the sequence of disassembly steps. In addition, several indicators can be combined by formulating the respective assessment classes, e. g., a repair can be carried out by a generalist with a corresponding level of knowledge. Furthermore, not all indicators are logically applicable to all products. Instead, the indicators applicable to a product should be selected. Indicators concerning software and firmware are equivalent to spare parts. This indicator is particularly relevant for information and communication technology (ICT) equipment.

Table 15: Overview of potential repairability indicators

Dimension	Indicator	Approach (Reference)	Assessment level		Comparison with DIN EN 45554
			Product	Part	
D: Disassembly					
	D1: Steps (Depth)	Cordella et al. (2019), Repairability Indicator, repairability.org, eDiM, Kroll	X		Disassembly depth
	D2: Time (Person)	U-effort, Philips ECC, Desai&Mital, Kroll, eDiM	X		
	D3: Accessibility	Cordella et al. (2019), Repairability Indicator, repairability.org	X		
	D4: Open & replace	iFixit	X		
C: Attachments/ fasteners					
	C5: Amount	eDiM	X		
	C6: Type	Cordella et al. (2019), iFixit, repair-ability.org, U-effort, Philipps ECC	X		Types of fasteners
	C7: Visibility	Repairability Indicator, repairability.org, Blue Angel, eDiM	X		
T: Tools					x
	T8: Actor		X		
	T9: Type	Bracquené et al. (2018),	X		Required tools

Dimension	Indicator	Approach (Reference)	Assessment level		Comparison with DIN EN 45554
		Repairability Indicator, ONR 192192:2014, repairability.org, Blue Angel, eDiM, Cordella et al. (2019)			
	T10: Amount	Bracquené et al. (2018), Cordella et al. (2019)	X		
	T11: Costs		X		
F: Fault diagnosis					
	F12: Type	Bracquené et al. (2018), ONR 192102:2014	X		Diagnostic support and interfaces
	F13: Interface	Cordella et al. (2019), Bracquené et al. (2018), ONR 192102:2014	X		
	F14: Equipment	Repairability Indicator, repairability.org	X		
I: Information					
	I15: Actor	Cordella et al. (2019), ONR 192192:2014	X	X	Types and availability of information by target groups
	I16: Type	Bracquené et al. (2018), Repairability Indicator, repairability.org, ONR 192102:2014, Cordella et al. (2019)	X	X	
	I17: Scope	Cordella et al. (2019)	X	X	Types and availability of information by compre-hensiveness
S: Spare parts					
	S18: Actor	Bracquené et al. (2018), ONR 192102:2014,	X		Availability of spare parts by target group

Dimension	Indicator	Approach (Reference)	Assessment level		Comparison with DIN EN 45554
		Repairability Indicator, repairability.org, Cordella et al. (2019)			
	S19: Type	Cordella et al. (2019), Benelux, ONR 192102:2014	X		Availability of spare parts by spare part interfaces
	S20: Availability duration	Cordella et al. (2019), Bracquené et al. (2018), Blue Angel ONR 192102:2014, EU Ecolabel	X		Availability of spare parts by duration of availability
	S21: Costs	Bracquené et al. (2018), Repairability Indicator, repairability.org			
	S22: Delivery time (Procurement duration)	Repairability Indicator, repairability.org, ONR 192102:2014			
SF: Software/ Firmware					
	SF23: Actor SF24: Installation effects SF25: Costs SF26: Availability duration				Data transfer and deletion
K: Knowledge					
	K27: Actor	Cordella et al. (2019)		X	Skill level
	K28: Skill level	Repairability Indicator, repairability.org		X	
W: Working environment					

Dimension	Indicator	Approach (Reference)	Assessment level		Comparison with DIN EN 45554
	W29: Place	Cordella et al. (2019)		X	Working environment
	W30: Safety	Repairability Indicator, repairability.org		X	
	W31: Disposal of defective parts	Repairability Indi-cator, repairability.org, ONR 192102:2014			
DP: Data / Password					
	DP32: Data deletion	Cordella et al. (2019)	X		Password and factory reset for reuse
	DP33: Password reset	Cordella et al. (2019), ONR 192102:2014	X		
M: Manu-facturer service					
	M34: Return models	Cordella et al. (2019), Bracquené et al. (2018), EU Ecolabel		X	Return models
	M35: Manufacturer warranty duration	Bracquené et al. (2018)			
	M36: Effects of repair on warranty	Repairability Indicator, repairabilit.org			
	M37: Manufacturer support	Bracquené et al. (2018), ONR 192102:2014			

Source: Own depiction

The following section describes individual central aspects of the dimensions listed in Table 15 and, in some cases, individual indicators in more detail:

- Disassembly

  The disassembly depth is the absolute number of work steps required to remove a defective part from a device. The analysis of the disassembly depth is fundamental to evaluate the effort required to replace a defective part. This requires a definition of what is meant by a step, i. e., when the step begins and when it ends. For example, a tool change or the removal of a part could be evaluated as a disassembly step. The determination of the assessment class depends on the minimum and maximum number of disassembly steps of the products on the market. The time required for disassembly is relevant as well. It depends not only on the depth of disassembly, but also on the person carrying out the repair and numerous other factors, e. g., identifiability of parts. Accordingly, a repair is likely to be carried out much more quickly by a professional repair company than by a private individual. The accessibility of a part is indirectly included in these two indicators, since it logically follows that the number of disassembly steps and the total disassembly time will probably increase for parts that are difficult to access and can thus be assessed objectively rather than subjectively by these two indicators. Naturally, disassembly must always be reversible (non-destructive) so that reassembly is possible afterwards.

- Attachments/fasteners

Connecting elements link the individual components of a device. These play a central role in the disassembly of a product. Adhesive joints, for instance, can prevent reversible disassembly. In addition to the type of connection, however, the number of fasteners and their visibility also play a role, as they influence the overall duration of a repair.

- Tools

The type and number of tools required for a repair can easily be influenced by the manufacturing company, as different tools are required depending on the fasteners used. However, what is meant by a common tool, for example, also depends on the repairing person. Professional repairers usually have different equipment than private individuals.

- Fault diagnosis

Fault diagnosis facilitates the identification of the defect. A product interface designed for this purpose is usually necessary to display the error, e. g., via a numerical code.

- Information

Information can facilitate the repair process. It matters whether it is free of charge or subject to a fee, what kind of information is available, to what extent it is available, for what period of time and for which actors it is available. The type and comprehensiveness of information is related to a variety of other indicators, such as what tools are needed for the repair, through which channels spare parts can be obtained, what the disassembly sequence looks like and what working environment is required. Conflicts can arise, however, if certain information, especially in relation to product design, is treated as confidential by the manufacturing companies and thus not publicly available.

- Spare parts

The availability of spare parts is a key requirement to successfully repair a product. The price of spare parts is often a decisive criterion as to whether a repair can be carried out profitably by a repair company. However, absolute prices are not useful within the European Union due to different price levels. Relative prices, such as the cost of spare parts in relation to the country-specific new product price, are an alternative. The period of spare parts availability usually depends on the product lifetime. For example, under normal use, a washing machine will fail at a much later stage than a vacuum cleaner. If safety risks arise when replacing a part, it may be reasonable to make this part accessible only to certain repair agents - rather than making all other spare parts inaccessible due to these safety concerns.

- Software/Firmware

Indicators related to software or firmware are almost equivalent to those related to spare parts, but only refer to specific devices, mainly ICT devices.

- Knowledge

  Carrying out any repair requires technical knowledge, for example to identify the fault, to get access to the defective part and the correct use of tools. To promote repair, defective products should be repairable by the widest possible range of actors, including repair cafés, which play a key role in raising awareness among the population. Nevertheless, risks that arise during or as a result of repair should not be ignored.

- Working environment

  The working environment determines what environment is required for a repair. Some repairs may require a special working environment due to safety risks. Where a safety risk exists, the manufacturing company should draw attention to it by providing appropriate information. However, what constitutes a risk must be defined on a product-specific basis.

- Data/Password

  Data deletion and password resets play a central role, especially if the user changes after the repair, e. g., due to a change of service laptop within an organization or the sale of a smartphone to a commercial enterprise.

3.4 Discussion of approaches for assessing repairability

Each of the mentioned systems for assessing repairability has its specific advantages and disadvantages, yet the analysis illustrates several points that need to be considered when developing repair indicators:

First, numerous dimensions influence whether a product is or can be repaired. They address different aspects of a repair, such as:

- Economic factors, e. g., costs for spare parts, costs for tools, costs for labor or eventually costs for travel.
- Technical factors, e. g., product design, non-destructive dismantling, availability of spare parts.
- Organizational factors, e. g., availability of repair workshops, time required to complete the repair, access to information.
- Legal factors, e. g., guarantee, warranty, safety.
- Behavioral factors, e. g., emotional importance of a product, awareness of repair options, dispensability of a product for the time of repair.

The approaches analyzed so far focus primarily on economic, technical and organizational aspects of repair. Legal and behavioral factors are barely specified.

Secondly, the assessment of repairability must be based exclusively on objective criteria that can be verified - and not on subjective ones. This should be considered when formulating the assessment classes. However, although some indicators are theoretically relevant for repair, objective operationalization is not always possible. An example of this is accessibility to parts. This is difficult to define objectively because it depends, for example, subjectively on the experience level of the person doing the repair.

Thirdly, an evaluation must be possible at the time a product is placed on the market. This poses a special challenge, for example, when assessing the availability of spare parts, because it must be proven that this can be guaranteed in the future for the specified period of time. In this context, the question arises to what extent a stockpile that may not be utilized can be justified regarding resource protection.

Fourthly, economic factors are often a decisive criterion for whether a repair is carried out at all. However, this poses a challenge for a uniform evaluation system within the European Union. This is because absolute values are not useful, as the costs of repair services, for example, can vary greatly between member states. For spare parts, relative values in relation to the new price of a product could be used instead, as is the case with the French Repair Index. It is of course also conceivable that relative values for repair costs as a whole are used, such as "repairing defect X may cost a maximum of Y percent of the new price".

Fifthly, there must be continuous monitoring to check the accuracy of the information provided, especially if the classification of repairability is made exclusively by the manufacturing company. In the case of violations, a sanction mechanism is required that entails tangible (financial) consequences in the event of a false declaration by the manufacturing company.

Finally, it must be noted that although a labelling obligation ensures more transparency on the part of the prospective buyers, it does not necessarily lead to more sustainable purchasing behavior. Numerous recent social science studies make clear that even if there is an awareness of a certain environmental problem, this awareness cannot be translated into corresponding action (so-called *attitude-behavior gap*). This gap between knowledge and action, although not yet empirically verified, could also apply to purchasing and repair. Thus, labelling can only be one of several measures (besides e. g., reduced VAT rate[10], creation of easily accessible repair offers, establishment of a repair culture) to promote repair as a waste prevention measure.

[10] e. g., Schulze et al. (2017)

4 Case studies to verify the applicability of the indicators for printers and tumble dryers

In this project, practical case studies were carried out on electrical and electronic equipment. The objectives of the case studies include the following key points:

- ► The standard EN 45554 developed under the standardization mandate M543 was to be tested, in particular the informatively presented example of a scoring system, for its practical suitability in order to gain knowledge for updating the standard.
- ► The theoretically possible repair indicators developed in this project were to be checked for their practical applicability. The development of an optimised scoring system for repairability should be supported by the case studies.

Requirements and indicators that can be used in product policy instruments in the future, such as the "Blauer Engel" (Blue Angel) and the Ecodesign Directive, were to be identified with the help of the case studies. The objective is to use them in product policy instruments in an optimized way in the future. Furthermore, the case studies support the development of recommendations for actions to the client.

In the following subchapters, the selection of the product groups for the case studies, the indicators to be included and the procedures are presented. The results of the case studies on printers (see section 4.4) and dryers (see section 4.5) are then explained.

4.1 Selection of product groups

The product groups for the case studies were selected together with the client. The product groups tumble dryers and printers were selected. This selection of product groups from the fields of information and communication technology as well as household appliances is intended to achieve broad coverage of design aspects.

Tumble dryers are considered to have a high resource saving potential in the 3rd working plan for the Ecodesign Directive (2016-2019). In addition, a revision study on tumble dryers was underway at EU level at the time of the product group selection.

Printers and multifunctional devices are part of the product world of the "Blauer Engel" eco-label and are highly relevant for the eco-label.

4.2 Selection of indicators

The indicators considered in the case studies were selected across product groups. Some of the selected indicators were investigated during practical investigations and some of them were researched.

Table 16 provides an overview of the indicators selected. For practical research reasons, the analysis was limited to these indicators in consultation with the client. On the one hand, the focus is on indicators that are included in the example of a scoring system in the EN 45554 standard. On the other hand, the focus is also on indicators that are part of the other existing approaches to assessing repairability (see chapter 3).

Table 16: Selected indicators

Indicator	Investigation	Assessment level
Disassembly depth (Number steps needed to remove apart from a product)	Practical investigation	Up to the priority part
Time for disassembly	Practical investigation	Up to the priority part
Fasteners	Practical investigation	Up to the priority part
Visibility of fasteners (in brief)	Practical investigation	Product
Number of tools	Practical investigation	Up to the priority part
Number of tool changes	Practical investigation	Up to the priority part
Types of tools	Practical investigation	Product
Skill level / knowledge	Practical investigation	Product
Working environment	Practical investigation	Product
Availability of repair information (per target group)	Research	Product
Type of interface / Diagnostic interface	Research	Product
Identification of spare parts	Research	Product
Availability of spare parts (per target group) (randomly tested)	Research	Product
Delivery time for spare parts (randomly tested)	Research	Product
Spare parts costs (randomly tested)	Research	Product
Availability of software / firmware (per target group)	Research	Product
Restoring of factory settings	Research	Product

Source: Own presentation

4.3 Approach

As described before, the case studies included **practical investigations** as well as **research**.

During the practical investigations, the selected priority parts were disassembled and the indicators shown in Table 16 were documented.

The **practical investigations** for both printers and dryers were carried out by experienced repairers specialized in the respective product group. This procedure was chosen to exclude "learning effects" in terms of disassembly times. In the case of less experienced repairers, learning effects generally mean that the disassembly times become shorter and shorter from device to device. They are then no longer comparable. The technicians used here already had so much routine from daily practice, that the numbers of devices investigated in the project did not lead to further learning effects or time gains. Another advantage of using experienced repairers is that the documented disassembly times can be considered approximately relevant to practice. However, one limitation regarding practical relevance has to be noted. The practical investigations were carried out in workshops, where the devices were accessible from all sides. This is not always the case at the customer's premises.

1. Across product groups, the following activities performed on the way to the priority part were counted as one step:
   - removing a part,
   - unhooking, pulling aside or laying down of a part,
   - undoing of a set of screws necessary to proceed to the next step,
   - undoing of a set of similar fasteners, which is necessary to move to the next step,
   - tilting or angling the device to work on the underside,
   - pushing the device to the edge of the work surface to work on the underside.
2. Across product groups, the following elements undone on the way to the priority part, were counted as fasteners:
   - screws that have to be disconnected to reach the priority part,
   - noses that have to be disconnected to reach the priority part (e. g., by pushing down, or squeezing),
   - cable connections that have to be loosened to reach the priority part,
   - hooks or pins from which something is actively taken or pulled down,
   - snap rings / E-rings,
   - springs under tension.

Some parts have not been designated as fasteners because they do not transmit forces. These include, for example, springs that are under pressure, or guide lugs/pins that do not require deliberate disconnecting.

Different specifications of steps and fastening elements can lead to different results of repair and disassembly tests. Only tests with a uniform definition of working steps and fastening elements can be directly compared with each other.

The key findings of the practical investigations are described in subchapters 4.5.4 (printers) and 4.5.3 (dryers).

Further **research** was carried out on the selected devices on indicators that could not be tested directly on the devices. These related, for example, to spare parts, information availability, etc. The following sources of information were used:

- internet pages of manufacturers or their authorized service partners,

- product documents (user manuals, etc.),
- written and telephone inquiries with manufacturers or their authorized service partners.

The sources of information were used in a cascading manner wherever it made sense to do so. That means, inquiries and requests were made when the relevant information was not already publicly available, e. g., on the Internet. If there were any special features or deviations from this general approach to information gathering, they are briefly described in subsections 4.5.4 and 4.5.3 for the respective indicators.

In the course of the research and inquiries, it very quickly became clear that many manufacturers designate authorized service partners for Germany, who in many cases provide part of the customer service. They are available for inquiries and publish information on their websites. All information or parts, that are provided or could be obtained via manufacturers or their authorized service partners are classified as "available" for these case studies and lead to a positive assessment of a product. In contrast, a range of services offered by independent third parties (e. g., spare parts sales, provision of repair manuals) is not included in the assessment of a product.

During the research, it also became clear very quickly that manufacturers and authorized service partners treat requests from different actors differently. For example, certain information, such as a circuit diagrams, can only be obtained by actors who can prove that they are competent in repairs. In particular, lay persons are treated differently by manufacturers than their own authorized service partners. Therefore, actors are divided into three target groups for the case studies:

1. Lay person: non-professionals, without electrotechnical training.
2. Professional repairer: persons with electrical training who are not contractually linked to the manufacturer or authorised as service partners.
3. Authorised service partner: persons with electrical training who are contractually linked to the manufacturer.

For the distinction between target groups 1 and 2, it is always decisive to what extent repairers have a personal electrotechnical training and, if necessary, can prove it. This means, for example, that a trained electrician is always classified as a professional repairer, even if a request to a manufacturer could be made for private reasons instead of work-related reasons by the trained electrician. This also means, for example, that a repair café, in which only lay persons without electrical training work, falls under the target group lay person. A repair café in which an electrician carries out repairs by contrast, falls under the target group professional repairer.

It is also possible that a manufacturer runs an in-house repair service. Therefore, manufacturing companies and their authorized service partners are grouped together in the third target group.

These target groups are distinguished in this document in the presentation of results, in the discussion and also in the assessment of the repairability of devices, when appropriate.

4.4 Printers

In the following chapters the selection of devices and priority parts as well as the results of the practical investigations and of the research for the product group printers are described.

4.4.1 Selected devices

Once the product groups to be investigated had been agreed upon, it was determined together with the client which devices were to be investigated in the case studies. Since the project focuses on current product policy instruments, e. g., for regulating market access or quality labels for currently marketed devices, printers were selected that were being marketed in Germany at the time of the investigations. In addition, the focus of the case studies was on devices that can be used in private households.

When selecting printers, the three manufacturers with the highest market shares in Germany were considered, in order to cover as large a proportion as possible of the devices placed on the market. In addition, devices from the most relevant technologies (inkjet printers and laser printers) were considered for each manufacturer.

For each technology, one device each was selected in the lower and middle quality and price segments, to be able to identify any existing design differences during the case studies. This type of selection was deviated from, if a manufacturer did not offer a printer in the respective segment on the market.

When selecting the specific models, the printers that appeared in the bestseller lists of the major internet platforms were taken into account. Devices carrying the label Blauer Engel were given preferential consideration. Since the selection of models was based on market shares, the printers examined were multifunction devices that also had a scanning function.

Table 17 provides an overview of the selected devices per technology, manufacturer, model, existence of a Blue Angel and the suggested retail price (RRP).

Table 17: Printers selected for the case studies

Technology	Manufacturer	Model	Blauer Engel	RRP (€)
Color inkjet printer	Manufacturer 3	IJP5	No	73.11
Color inkjet printer	Manufacturer 3	IJP6	No	349.95
Color inkjet printer	Manufacturer 1	IJP1	No	89.99
Color inkjet printer	Manufacturer 1	IJP2	No	569.99
Color inkjet printer	Manufacturer 2	IJP3	No	59.99
Color inkjet printer	Manufacturer 2	IJP4	Yes	659.00
Monochrome laser printer	Manufacturer 3	LP3	No	249.00
Color laser printer	Manufacturer 3	LP4	Yes	629.00
Monochrome laser printer	Manufacturer 2	LP1	Yes	130.00
Color laser printer	Manufacturer 2	LP2	Yes	480.00

Source: Own depiction

4.4.2 Priority parts

In order to select priority parts for the practical investigations, the following sources of information were used:

- offers of spare parts in online stores,
- literature review,

- brief survey among selected repairers.

The findings were then coordinated with the experts from UBA and the priority parts listed in Table 18 were determined.

Table 18: Selected priority parts, printers

Inkjet printer	Laser printer
Print heads	Drive motor for paper transport
Internal power supply unit	Main memory
External power supply unit	Feed rollers
Parts for sheet feeder	Fixing unit
Ink sponge	Laser unit
	Paper tray
	Separation rollers, -pads
	Control board and display
	External power supply unit
	Internal power supply unit
	Transfer belt
	Transfer unit
	Drum unit
	Closing lid

Source: Own depiction

4.4.3 Practical investigations

In this subsection key data from the practical investigations are summarised in table form and key findings are presented.

First of all, it should be noted that the external power supply units for inkjet printers as well as an (individually installed) main memory for laser printers were not found in any of the printers examined. The external power supply units were exclusively located in the devices and the main memory was permanently installed on the circuit boards in all cases. These parts are therefore not considered further for the following evaluations.

For future studies, it can be assumed that these parts no longer play a prominent role in newly marketed devices. Their mention by the repairers in the survey could be due to the fact that the respondents work on somewhat older devices in their practice.

4.4.3.1 Inkjet printers

For the **inkjet printers** examined, the data on the remaining priority parts is shown in Table 19. If parts are not present in a printer model, “n/p” is indicated for “not present”.

Table 19: Indicators for practical investigations, inkjet printer

	Manufac-turer 3, IJP5	Manufac-turer 3, IJP6	Manufac-turer 1, IJP1	Manufac-turer 1, IJP2	Manufac-turer 2, IJP3	Manufact-urer 2, IJP4
	Print heads	Print heads	Print heads	Print heads	Print heads	Print heads
Number of fasteners	0	0	12	11	0	79
Thereof screws	0	0	4	4	0	40
Number of tools	0	0	3	3	0	3
Number of uses of tools	0	0	5	5	0	18
Number of tool changes	0	0	3	3	0	6
Number of steps	2	3	14	15	3	59
Disassembly time (hh:mm:ss)	00:00:20	00:00:20	00:05:00	00:08:00	00:00:15	01:30:00
	Feed roller document feeder	Feed roller document feeder	Feed roller document feeder	Feed roller document feeder	Feed roller document feeder	Feed roller document feeder
Number of fasteners	n/p	n/p	n/p	0	n/p	1
Thereof screws	n/p	n/p	n/p	0	n/p	1
Number of tools	n/p	n/p	n/p	1	n/p	2
Number of uses of tools	n/p	n/p	n/p	1	n/p	3
Number of tool changes	n/p	n/p	n/p	0	n/p	1
Number of steps	n/p	n/p	n/p	5	n/p	8
Disassembly time (hh:mm:ss)	n/p	n/p	n/p	00:01:00	n/p	00:03:00
	Feed roller stack sheet feeder (top)	Feed roller stack sheet feeder (top)	Feed roller stack sheet feeder (top)	Feed roller stack sheet feeder (top)	Feed roller stack sheet feeder (top)	Feed roller stack sheet feeder (top)
Number of fasteners	n/p	n/p	7	n/p	n/p	n/p
Thereof screws	n/p	n/p	3	n/p	n/p	n/p

	Manufac-turer 3, IJP5	**Manufac-turer 3, IJP6**	**Manufac-turer 1, IJP1**	**Manufac-turer 1, IJP2**	**Manufac-turer 2, IJP3**	**Manufact-urer 2, IJP4**
Number of tools	n/p	n/p	2	n/p	n/p	n/p
Number of uses of tools	n/p	n/p	4	n/p	n/p	n/p
Number of tool changes	n/p	n/p	2	n/p	n/p	n/p
Number of steps	n/p	n/p	12	n/p	n/p	n/p
Disassembly time (hh:mm:ss)	n/p	n/p	00:03:00	n/p	n/p	n/p
	Feed roller stack sheet feeder (bottom)	Feed roller stack sheet feeder (bottom)	Feed roller stack sheet feeder (bottom)	Feed roller stack sheet feeder (bottom)	Feed roller stack sheet feeder (bottom)	Feed roller stack sheet feeder (bottom)
Number of fasteners	10	48	2	2	30	3
Thereof screws	2	19	1	0	30	1
Number of tools	3	2	2	0	3	2
Number of uses of tools	3	13	2	0	8	3
Number of tool changes	2	5	1	0	3	1
Number of steps	11	37	6	7	22	8
Disassembly time (hh:mm:ss)	00:05:00	00:30:00	00:01:30	00:01:30	00:20:00	00:02:00
	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder
Number of fasteners	n/p	n/p	n/p	6	n/p	8
Thereof screws	n/p	n/p	n/p	4	n/p	2
Number of tools	n/p	n/p	n/p	2	n/p	2
Number of uses of tools	n/p	n/p	n/p	2	n/p	4
Number of tool changes	n/p	n/p	n/p	1	n/p	2
Number of steps	n/p	n/p	n/p	6	n/p	8

	Manufac-turer 3, IJP5	**Manufac-turer 3, IJP6**	**Manufac-turer 1, IJP1**	**Manufac-turer 1, IJP2**	**Manufac-turer 2, IJP3**	**Manufact-urer 2, IJP4**
Disassembly time (hh:mm:ss)	n/p	n/p	n/p	00:03:00	n/p	00:01:30
	Separation pad stack sheet feeder	Separation pad stack sheet feeder	Separation pad stack sheet feeder	Separation pad stack sheet feeder	Separation pad stack sheet feeder	Separation pad stack sheet feeder
Number of fasteners	n/p	n/p	n/p	n/p	n/p	1
Thereof screws	n/p	n/p	n/p	n/p	n/p	1
Number of tools	n/p	n/p	n/p	n/p	n/p	1
Number of uses of tools	n/p	n/p	n/p	n/p	n/p	1
Number of tool changes	n/p	n/p	n/p	n/p	n/p	0
Number of steps	n/p	n/p	n/p	n/p	n/p	4
Disassembly time (hh:mm:ss)	n/p	n/p	n/p	n/p	n/p	00:01:30
	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit
Number of fasteners	2	1	10	10	3	46
Thereof screws	0	0	2	3	2	14
Number of tools	0	0	2	2	1	2
Number of uses of tools	0	0	5	3	1	9
Number of tool changes	0	0	3	1	0	2
Number of steps	4	3	13	8	5	27
Disassembly time (hh:mm:ss)	00:00:10	00:00:10	00:05:00	00:03:00	00:00:45	00:25:00
	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge
Number of fasteners	10	47	1	1	2	4
Thereof screws	3	18	1	1	2	4

	Manufac-turer 3, IJP5	Manufac-turer 3, IJP6	Manufac-turer 1, IJP1	Manufac-turer 1, IJP2	Manufac-turer 2, IJP3	Manufact-urer 2, IJP4
Number of tools	2	2	1	1	1	1
Number of uses of tools	3	12	1	1	1	1
Number of tool changes	2	5	0	0	0	0
Number of steps	11	34	3	3	3	4
Disassembly time (hh:mm:ss)	00:03:00	00:27:00	00:01:00	00:00:30	00:01:00	00:01:30

Source: Own depiction

When looking at the results, the first thing that stands out is that the selected priority parts "parts for sheet feeder" are basically found in the printers examined for three feeder formats. All three feeders can have feed rollers and separation pads or units.

However, all three sheet feeder formats only occur simultaneously in a few printer models. This is also due to the fact that in some cases only the "normal" stacked sheet feeder is supported by the printer. In the following, we will therefore only take a closer look at the stack sheet feeder in order to make the printer models comparable with each other and not to negatively evaluate the devices with more functions because they have more functions.

As a rough guide for comparison between printers, the indicators considered can be summed up for several priority parts. This is only possible for priority parts that occur in all printer models. In general, this also means that printer models with a different range of services, e. g., with regard to special formats, are relatively difficult to compare with each other. In this case, the following priority parts occur in all printer models examined:

- print heads,
- feed roller for the stack sheet feeder (bottom),
- internal power supply unit,
- ink sponge.

For these four priority parts, the totals of the indicators are shown in Table 20.

Table 20: Totals of indicators for comparable priority parts, inkjet printers

Total indicators	Manufact-urer 3, IJP5	Manufact-urer 3, IJP6	Manufact-urer 1, IJP1	Manufact-urer 1, IJP2	Manufact-urer 2, IJP3	Manufact-urer 2, IJP4
Total fasteners	22	96	25	24	35	132
Total screws	5	37	8	8	34	59
Total tools	5	4	8	6	5	8

Total indicators	Manufact-urer 3, IJP5	Manufact-urer 3, IJP6	Manufact-urer 1, IJP1	Manufact-urer 1, IJP2	Manufact-urer 2, IJP3	Manufact-urer 2, IJP4
Total uses of tools	6	25	13	9	10	31
Total tool changes	4	10	7	4	3	9
Total steps	28	77	36	33	33	98
Total disas-sembly times	00:08:30	00:57:30	00:12:30	00:13:00	00:22:00	01:58:30
RRP (€)	73.11	349.95	89.99	569.99	59.99	659.00

Source: Own depiction

The totals of the disassembly times range from about 8 minutes to about 2 hours. In this simplified assessment, printer IJP5 of manufacturer 3 has the lowest total in disassembly times, followed by printer IJP1 of manufacturer 1, printer IJP2 of manufacturer 1, and printer IJP3 of manufacturer 2.

In the case of the printer with the fourth-best total disassembly time, it is not quite three times as high as in the case of the printer with the lowest total disassembly time. The IJP6 models from manufacturer 3 and IJP4 from manufacturer 2 follow at a considerable distance. The total of the disassembly time is approx. seven times (IJP6 from manufacturer 3) and approx. fourteen times (IJP4 from manufacturer 2) the total of the disassembly time of the printer with the lowest total.

With regard to the IJP6 printer from manufacturer 3, the fact that the ink sponge is only accessible after the printer has been largely dismantled has an unfavourable effect. The IJP4 printer from manufacturer 2 is particularly affected by the fact that the print heads are not integrated in the ink cartridges, as is the case with many other models, but in the print unit. With this printer model, a second person was used for the work for a short time.

Of the inkjet printers examined, the IJP4 model from manufacturer 2 carries the Blue Angel ecolabel. During the investigation it did not become clear that this leads to advantages in repairability. It should be noted in this context that the Blue Angel criteria do not explicitly address repairability.

In the case of inkjet printers, there is a linear correlation between the sum of the times for disassembly and the number of steps. The correlation coefficient is r = 0.967. Furthermore, the sum of disassembly times correlates with the sum of fasteners (r = 0.976). With regard to the formation of the correlation coefficient, it must be noted that only a small number of data points are compared with each other. Overall, however, it can be stated that in the practical investigations with the inkjet printers examined here, a higher number of work steps as well as fastening elements also led to higher actual times for disassembly.

There is no correlation between the RRP of the inkjet printers and the total disassembly times (r = 0.257).

4.4.3.2 Laser printers

For the **laser printers** examined, the data on the remaining priority parts are shown in Table 21. If components are not present in a printer model, “n/p” is indicated for “not present”.

Table 21: Indicators for practical investigations, laser printers

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
	Drum unit	Drum unit	Drum unit	Drum unit
Number of fasteners	0	0	0	0
Thereof screws	0	0	0	0
Number of tools	0	0	0	0
Number of uses of tools	0	0	0	0
Number of tool changes	0	0	0	0
Number of steps	6	5	2	3
Disassembly time (hh:mm:ss)	00:01:00	00:00:30	00:00:10	00:00:15
	Feed rollers document feeder	Feed rollers document feeder	Feed rollers document feeder	Feed rollers document feeder
Number of fasteners	n/p	2	n/p	n/p
Thereof screws	n/p	0	n/p	n/p
Number of tools	n/p	1	n/p	n/p
Number of uses of tools	n/p	3	n/p	n/p
Number of tool changes	n/p	0	n/p	n/p
Number of steps	n/p	16	n/p	n/p
Disassembly time (hh:mm:ss)	n/p	00:02:30	n/p	n/p
	Feed rollers special format feeder	Feed rollers special format feeder	Feed rollers special format feeder	Feed rollers special format feeder
Number of fasteners	n/p	2	n/p	0
Thereof screws	n/p	0	n/p	0
Number of tools	n/p	1	n/p	1
Number of uses of tools	n/p	0	n/p	1
Number of tool changes	n/p	0	n/p	0
Number of steps	n/p	5	n/p	3
Disassembly time (hh:mm:ss)	n/p	00:00:30	n/p	00:00:30
	Feed rollers stack sheet feeder	Feed rollers stack sheet feeder	Feed rollers stack sheet feeder	Feed rollers stack sheet feeder
Number of fasteners	2	0	0	0

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Thereof screws	0	0	0	0
Number of tools	1	0	1	0
Number of uses of tools	1	0	1	0
Number of tool changes	0	0	0	0
Number of steps	8	13	3	11
Disassembly time (hh:mm:ss)	00:01:30	00:02:00	00:01:00	00:01:30
	Transfer roll	Transfer roll	Transfer roll	Transfer roll
Number of fasteners	1	4	2	4
Thereof screws	0	0	0	0
Number of tools	1	1	1	1
Number of uses of tools	1	0	1	1
Number of tool changes	0	0	0	0
Number of steps	8	9	4	3
Disassembly time (hh:mm:ss)	00:01:00	00:01:00	00:01:00	00:01:00
	Transfer unit	Transfer unit	Transfer unit	Transfer unit
Number of fasteners	52	39	n/p	3
Thereof screws	17	9	n/p	1
Number of tools	2	3	n/p	2
Number of uses of tools	9	7	n/p	2
Number of tool changes	4	5	n/p	1
Number of steps	38	22	n/p	5
Disassembly time (hh:mm:ss)	00:18:00	00:05:30	n/p	00:01:30
	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder	Separation pad document feeder
Number of fasteners	n/p	2	n/p	n/p
Thereof screws	n/p	0	n/p	n/p
Number of tools	n/p	1	n/p	n/p
Number of uses of tools	n/p	1	n/p	n/p
Number of tool changes	n/p	0	n/p	n/p
Number of steps	n/p	4	n/p	n/p

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Disassembly time (hh:mm:ss)	n/p	00:00:10	n/p	n/p
	Separation rollers document feeder	Separation rollers document feeder	Separation rollers document feeder	Separation rollers document feeder
Number of fasteners	n/p	5	n/p	n/p
Thereof screws	n/p	0	n/p	n/p
Number of tools	n/p	1	n/p	n/p
Number of uses of tools	n/p	3	n/p	n/p
Number of tool changes	n/p	0	n/p	n/p
Number of steps	n/p	18	n/p	n/p
Disassembly time (hh:mm:ss)	n/p	00:03:00	n/p	n/p
	Separation pad special format feeder	Separation pad special format feeder	Separation pad special format feeder	Separation pad special format feeder
Number of fasteners	n/p	2	n/p	0
Thereof screws	n/p	0	n/p	0
Number of tools	n/p	1	n/p	1
Number of uses of tools	n/p	1	n/p	1
Number of tool changes	n/p	0	n/p	0
Number of steps	n/p	5	n/p	3
Disassembly time (hh:mm:ss)	n/p	00:00:30	n/p	00:00:30
	Separation rolls stack sheet	Separation rolls stack sheet	Separation rolls stack sheet	Separation rolls stack sheet
Number of fasteners	2	4	n/p	0
Thereof screws	2	0	n/p	0
Number of tools	1	1	n/p	0
Number of uses of tools	0	1	n/p	0
Number of tool changes	0	0	n/p	0
Number of steps	11	14	n/p	9
Disassembly time (hh:mm:ss)	00:01:00	00:02:30	n/p	00:01:30
	Paper tray	Paper tray	Paper tray	Paper tray
Number of fasteners	20	69	11	60

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Thereof screws	3	28	4	21
Number of tools	3	2	2	2
Number of uses of tools	6	18	3	17
Number of tool changes	5	10	2	10
Number of steps	26	49	15	51
Disassembly time (hh:mm:ss)	00:08:00	00:23:00	00:07:00	00:25:00
	Closing lid	Closing lid	Closing lid	Closing lid
Number of fasteners	30	49	0	32
Thereof screws	5	16	0	4
Number of tools	2	2	1	3
Number of uses of tools	8	7	1	8
Number of tool changes	5	4	0	6
Number of steps	26	24	4	26
Disassembly time (hh:mm:ss)	00:08:00	00:15:00	00:00:20	00:12:00
	Laser unit	Laser unit	Laser unit	Laser unit
Number of fasteners	46	110	36	73
Thereof screws	13	53	24	27
Number of tools	3	2	2	3
Number of uses of tools	9	31	5	21
Number of tool changes	6	13	2	11
Number of steps	42	84	26	66
Disassembly time (hh:mm:ss)	00:15:00	00:45:00	00:12:00	00:30:00
	Transfer belt	Transfer belt	Transfer belt	Transfer belt
Number of fasteners	n/p	47	n/p	30
Thereof screws	n/p	13	n/p	6
Number of tools	n/p	2	n/p	3
Number of uses of tools	n/p	8	n/p	10
Number of tool changes	n/p	4	n/p	7
Number of steps	n/p	33	n/p	29
Disassembly time (hh:mm:ss)	n/p	00:11:00	n/p	00:20:00
	Fixing unit	Fixing unit	Fixing unit	Fixing unit

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Number of fasteners	61	114	48	74
Thereof screws	21	48	34	26
Number of tools	2	2	2	2
Number of uses of tools	11	22	8	18
Number of tool changes	6	10	2	10
Number of steps	44	65	33	54
Disassembly time (hh:mm:ss)	00:21:00	00:50:00	00:15:00	00:26:00
	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit
Number of fasteners	28	29	43	46
Thereof screws	9	12	26	14
Number of tools	2	2	2	2
Number of uses of tools	6	5	8	10
Number of tool changes	4	2	3	6
Number of steps	25	17	31	30
Disassembly time (hh:mm:ss)	00:09:00	00:09:00	00:15:00	00:22:00
	Display and control board	Display and control board	Display and control board	Display and control board
Number of fasteners	9	16	n/p	61
Thereof screws	3	8	n/p	19
Number of tools	2	2	n/p	2
Number of uses of tools	2	7	n/p	17
Number of tool changes	1	5	n/p	9
Number of steps	6	19	n/p	48
Disassembly time (hh:mm:ss)	00:01:30	00:05:00	n/p	00:25:00
	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed
Number of fasteners	90	53	58	49
Thereof screws	37	17	40	15
Number of tools	2	2	2	2
Number of uses of tools	15	8	12	12

	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Number of tool changes	8	4	4	8
Number of steps	58	25	43	35
Disassembly time (hh:mm:ss)	00:25:00	00:12:00	00:21:00	00:24:00

Source: Own depiction

Again, it is noticeable that the printer models differ with regard to existing priority parts. This applies in particular to the feed rollers and separation pads or units.

As with the inkjet printers, a simplified comparison of totals can only make sense for the priority parts that are present in all the laser printers examined. These are in this case:

- drum unit,
- feed rollers (stacked sheet feeder),
- transfer roller,
- paper tray,
- closing lid,
- laser unit,
- fixing unit,
- internal power supply unit,
- drive motor for paper feed.

For these nine priority parts, the totals of the indicators considered are shown in Table 22

Table 22: Totals of indicators for comparable priority parts, laser printers

Total indicators	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Total fasteners	278	428	198	338
Total screws	88	174	128	107
Total tools	16	13	13	15
Total uses of tools	57	91	39	87
Total tool change	34	43	13	51
Total steps	243	291	161	279
Total disassembly time	01:29:30	02:37:30	01:12:30	02:21:45
RRP (€)	249.00	629.00	130.00	480.00

Source: Own depiction

The total disassembly times range from approx. 1 hour and 12 minutes to 2 hours and 37 minutes.

The LP1 printer from manufacturer 2 has the lowest total disassembly time and also the lowest number of fasteners and work steps. When looking at the other laser printers, a correlation between a higher total of fasteners and a higher total of disassembly times is also confirmed. With regard to fasteners, there is a linear correlation with the time for disassembly. The correlation coefficient is r = 0.96.

The correlation coefficient between the sum of the work steps and the sum of the disassembly times is r = 0.789. The printer with the most work steps also has the highest disassembly time. While this linear correlation is somewhat less strong, the rankings (1st place, 2nd place...) of the printers in terms of work steps and disassembly times are identical.

With regard to the formation of the correlation coefficient and the consideration of the rankings, it must be noted that only a very small number of values are compared with each other.

Overall, however, it can be stated that in the practical investigations with the laser printers examined here, a higher number of work steps and fastening elements also led to higher actual disassembly times.

A correlation can be established between the RRP of the individual laser printers and the total disassembly times. The cheapest laser printer has the lowest total disassembly time and the most expensive laser printer the highest total disassembly time. The correlation coefficient is r = 0.957. For the laser printers in this study, therefore, the sum of the disassembly times increases with a higher RRP. This could be related to the fact that devices become more complex with increasing RRP. However, it must also be noted here, that the number of data points considered is very small. Furthermore, a correlation between RRP and disassembly times only occurs for laser printers and not for other equipment groups in these case studies.

4.4.3.3 Conclusions for indicators

Based on the results of the case studies, conclusions can be drawn as to which indicators should be adopted in an optimised scoring system. In connection with the practical investigations, the nine indicators shown in Table 16 were examined. Below, we discuss which of these indicators will be included in the optimised scoring system. An important question is whether there are indicators for which a correlation (as linear as possible) to the actual disassembly time is found. Such an indicator could be a proxy for the disassembly time in a scoring system. In this way, serial tests with time recordings on devices do not have to be carried out for the application of the scoring system.

For printers, as described previously, there is a linear relationship to disassembly time for both fasteners and steps. Both are potentially suitable for inclusion in the scoring system. In the case of laser printers, however, the correlation between the number of fasteners and the disassembly time is lower than the correlation between the number of work steps and the disassembly time.

Based on practical experience from the tests with printers, the indicator steps (or disassembly depth) is favoured for inclusion in an optimised scoring system. With regard to the fasteners, it repeatedly happened during the practical investigations that several fasteners (e. g., six plastic noses) could be loosened by a single movement. While this phenomenon is not relevant with screws, it occurs repeatedly with click connections. The indicator number of steps (or disassembly depth) can depict this phenomenon much better, as long as it is based on a suitable definition of a work step.

With regard to the fasteners, their type should be included in an optimised scoring system according to the results for printers. The indicator should show, whether fasteners can be removed and if they can be reused.

The visibility of fasteners, on the other hand, is not a relevant indicator according to the results for printers. All fastening elements were clearly visible and identifiable. Hidden fasteners or special features did not stand out. Furthermore, it is not clear how an objective assessment of visibility should be made. An indicator for the visibility of fasteners should therefore not be included in an optimised scoring system according to the findings on printers.

With regard to tools, their classes, number and the number of tool changes were investigated. The practical experience from the printer case studies has shown that many operations can be performed with a large number of different tools, e. g., with many different lever tools. A criterion to generally classify tools into good or less good tools cannot be derived from the case studies. The optimised scoring system should therefore only evaluate whether tools that are not available to some target groups (e. g., lay persons) are necessary for the repair. This would hinder repairs. The possibility of using many different types of tools for an operation also means that, based on the experience with printers, the number of tools or the number of tool changes should not be included in the optimised scoring system. If these indicators were applied, there could be conflicting goals. For example, a manufacturer could suggest in repair instructions to loosen a snap ring with a slotted screwdriver in order to minimize the number of tools and tool changes. This is not necessarily a good suggestion, because the probability of damaging the snap ring is lower when snap ring pliers are used.

The working environment should not be included in an optimised scoring system because it does not show differences between manufacturers. Provided that all printers are required to be repairable in private households, the working environment can be omitted from an optimised scoring system.

With regard to the knowledge required for the repair, it must be said that the work carried out could, at least theoretically, also have been carried out by lay persons. In this case, longer times for disassembly could be expected. No meaningful evaluation system was found that measures when a repair is no longer considered possible for certain actors. According to the findings on printers, an indicator for knowledge is not useful and should not be included in an optimised scoring system.

4.4.4 Research

In addition to the practical investigations, information on several possible indicators was gathered and evaluated. Sources used were for example user manuals, websites and inquiries with manufacturers. The general approach is described in chapter 4.3. Particularities of the research procedures and the procurement of information are described in the introductory sections of the following subchapters. Furthermore, the research results on possible indicators are presented. Finally, a brief assessment is given as to whether the results obtained for printers support inclusion of a possible indicator in an optimised scoring system or not.

4.4.4.1 Spare parts

As part of the printer case studies, the process of obtaining various spare parts for repairs was generally replicated. The information required for this was obtained and documented. With regard to spare parts, this includes in particular availability, delivery times and costs. Particular challenges and differences between manufacturers and models were noted. In this chapter the research on spare parts is presented.

4.4.4.1.1 Selection of spare parts

The selection of spare parts for the research was limited to the previously identified priority parts.

Care was taken to select parts and consumables with different characteristics. Table 23 below provides an overview of the selected parts.

Table 23: Selection of spare parts

Selected part	Characteristics
Ink cartridges (for inkjet printers) or drum units (for laser printers)	Consumables that are regularly changed by consumers and should be available to them.
Feed roller for the stack sheet feeder	Usually accessible without opening the printer housing and can be changed with relatively little technical knowledge. Is a so-called “replacement part” that must be available to users according to the criteria of the Blue Angel.
Print heads (for inkjet printers)	Depending on whether the print head is integrated in the ink cartridges or not, replacement usually requires more effort or is easy to perform.
Internal power supply unit	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Ink sponge (for inkjet printers)	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Transfer rollers (for laser printers)	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Paper tray (for laser printers)	Usually accessible without opening the housing and can be changed with relatively little technical knowledge.
Closing lid (for laser printers)	Usually accessible without opening the housing and can be changed with relatively little technical knowledge.
Laser unit (for laser printers)	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Fixing unit (for laser printers)	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Drive motor for paper feed (for laser printers)	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.

Source: Own depiction

4.4.4.1.2 Information gathering

To check the availability, delivery times, prices and costs of the selected printer spare parts, the following research steps were carried out:

- Research on website (manufacturers and authorised service partners).
- Written inquiries (e-mail and. chat) with manufacturers and authorised service partners.
- Telephone inquiries with manufacturers and authorised service partners.

As described in chapter 4.3 the information sources were used in a cascading manner. In this case, enquiries were started only if information on availability, delivery time and costs was not already publicly available in an internet shop for spare parts. Contacting the manufacturers or authorised service partners by telephone was carried out if there was a constant lack of written answers or if the answers were completely unclear with regard to the request.

The contacts in steps 2 and 3 were made as a private customer and as a professional repairer, who would like to obtain spare parts for the purpose of self-repair. In addition, we inquired about the repair services of the authorised service partners / manufacturers. Results from the latter inquiries, are used to assess the availability of spare parts for the target group of authorised service partners.

Furthermore, with regard to the possible indicator "duration of availability", contact was made as a consumer who might want to buy the respective printer model. The consumer then asked, whether the manufacturer can guarantee the availability of spare parts for the model for a certain period of time.

The answers were documented and are presented in the following subchapters.

4.4.4.1.3 Identifiability of spare parts

The first prerequisite for procuring spare parts is always that they can be clearly identified and matched to the correct printer model. Overcoming this first hurdle was sometimes very challenging. It quickly became clear, that the clear identification of spare parts depends on whether an exploded view is available that clearly shows the spare parts and their installation in the device. This exploded view is part of the information that may be provided for a printer model. Exploded views are therefore discussed in chapter 4.4.4.2.

4.4.4.1.4 Availability of spare parts

It was checked whether the selected spare parts (see Table 24) are available for repairs. This is initially independent of the costs of the spare parts or the delivery times. Inquiries were made in each case and it was documented which parts were made available to which three target groups of lay persons, professional repairer and authorised service partners (see chapter 4.3).

The results for inkjet printers are shown in the following Table 24.

Table 24: Availability of spare parts

Target Group	Manufacturer 3, IJP5	Manufacturer 3, IJP6	Manufacturer 1, IJP1	Manufacturer 1, IJP2	Manufacturer, IJP3	Manufacturer, IJP4
	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges
Lay person	Yes	Yes	Yes	Yes	Yes	Yes
Professional repairer	Yes	Yes	Yes	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes
	Print heads	Print heads	Print heads	Print heads	Print heads	Print heads
Lay person	Yes	Yes	Yes	No	Yes	Yes

Target Group	Manufac-turer 3, IJP5	Manufac-turer 3, IJP6	Manufac-turer 1, IJP1	Manufac-turer 1, IJP2	Manufac-turer, IJP3	Manufac-turer, IJP4
Professional repairer	Yes	Yes	Yes	No	Yes	Yes
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes
Information	Integrated in ink cartridges	/	/	/	Integrated in ink cartridges	/
	feed roller stacked sheet feeder	feed roller stacked sheet feeder	feed roller stacked sheet feeder	feed roller stacked sheet feeder	feed roller stacked sheet feeder	feed roller stacked sheet feeder
Lay person	No	Yes	Yes	Yes	No	Yes
Professional repairer	No	Yes	Yes	Yes	No	Yes
Authorised service partner	No	Yes	Yes	Yes	No	Yes
	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit
Lay person	No	Yes	Yes	Yes	No	No
Professional repairer	No	Yes	Yes	Yes	No	No
Authorised service partner	No	Yes	Yes	Yes	No	No
	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge
Lay person	No	Yes	Yes	Yes	No	Yes
Professional repairer	No	Yes	Yes	Yes	No	Yes
Authorised service partner	No	Yes	Yes	Yes	No	Yes

Source: Own depiction

When looking at Table 24, it is noticeable that the printer manufacturers make almost no distinction between the three target groups. Only for one printer a spare part (the print head) is made available to an authorised service partner, but not to lay persons or professional repairer. All other spare parts are either available or not available, regardless of the target group.

When looking at Table 24, it also becomes clear, that only the ink cartridges as consumables are made available for all inkjet printers.

For two printer models (manufacturer 3, IJP5 and manufacturer 2, IJP3), except for the ink cartridges (with the integrated print heads), none of the other selected spare parts are available.

For two other models (manufacturer 3, IJP6 and manufacturer 1, IJP1), all the selected spare parts are available for all target groups. For the remaining devices, some of the spare parts investigated are available and some are not.

Overall, it is noticeable that the availability of spare parts strongly depends on the printer model. For some models there is a very good supply of spare parts and for other models none at all.

The availability of spare parts is not handled in the same way by the manufacturers for all their models. It can happen that one manufacturer provides all the spare parts in question for one inkjet printer and only the ink cartridges and their integrated print heads for another inkjet printer.

There is also a correlation with the RRP of the devices. The availability of spare parts is worse for cheaper devices than for more expensive ones. The two inkjet printers for which only the ink cartridges are provided (manufacturer 3, IJP5 and manufacturer 2, IJP3) are also the two inkjet printers with the lowest RRP.

Results on the availability of the selected spare parts (see Table 23) for laser printers are shown in Table 25 below.

Table 25: Availability of spare parts, laser printers

Target group	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
	Drum unit	Drum unit	Drum unit	Drum unit
Lay person	Yes	Yes	Yes	Yes
Professional repairer	Yes	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes	Yes
	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder
Lay person	Yes	Yes	Yes	Yes
Professional repairer	Yes	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes	Yes
	Transfer roller	Transfer roller	Transfer roller	Transfer roller
Lay person	Yes	No	Yes	Yes
Professional repairer	Yes	No	Yes	Yes
Authorised service partner	Yes	No	Yes	Yes
	Paper tray	Paper tray	Paper tray	Paper tray
Lay person	Yes	Yes	No	Yes

Target group	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Professional repairer	Yes	Yes	No	Yes
Authorised service partner	Yes	Yes	No	Yes
	Closing lid	Closing lid	Closing lid	Closing lid
Lay person	Yes	Yes	No	Yes
Professional repairer	Yes	Yes	No	Yes
Authorised service partner	Yes	Yes	No	Yes
	Laser unit	Laser unit	Laser unit	Laser unit
Lay person	Yes	Yes	No	Yes
Professional repairer	Yes	Yes	No	Yes
Authorised service partner	Yes	Yes	No	Yes
	Fixing unit	Fixing unit	Fixing unit	Fixing unit
Lay person	Yes	Yes	No	Yes
Professional repairer	Yes	Yes	No	Yes
Authorised service partner	Yes	Yes	No	Yes
	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit
Lay person	Yes	Yes	No	Yes
Professional repairer	Yes	Yes	No	Yes
Authorised service partner	Yes	Yes	No	Yes
	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed
Lay person	No	Yes	No	Yes
Professional repairer	No	Yes	No	Yes
Authorised service partner	No	Yes	No	Yes

Source: Own depiction

When looking at Table 25, it is noticeable that the printer manufacturers do not make any distinctions between the three target groups. The selected spare parts for laser printers are uniformly provided or not provided for lay persons, professional repairer and authorised service partners. This supports this observation with regard to inkjet printers.

As Table 25 further shows, the drum units and feed rollers for the stacked sheet feeder are provided for all laser printers considered. For the LP1 model of manufacturer 2 only these two considered spare parts are available and for one model all considered spare parts are available. For the other two laser printers, the majority of parts are available. Just as with the inkjet printers, availability seems to be based on the printer model and not the manufacturer. As with the inkjet printers, the least expensive laser printer (manufacturer 2, LP1) has the fewest spare parts available.

None of the selected spare parts for inkjet or laser printers stand out because they are not provided by the manufacturers at all. The manufacturers also do not make any general statements about safety-relevant or non-safety-relevant spare parts leading to a different policy on spare parts availability. (In contrast, this is the case with dryers, see chapter 4.5.4.1.4).

The statement that the availability of spare parts is strongly model-dependent can therefore be generalised for inkjet and laser printers and was also confirmed by service staff in the course of the inquiries. It was mentioned several times that the availability depends on the price of the model, the sales figures of the model as well as the quality of the model (see also chapter 4.4.4.1.5).

While there are some printer models with very good and medium spare parts availability, there are also models for which almost no spare parts are provided. These models cannot be repaired even if a part fails. Thus, there seem to be models for which no repairs, at least those involving the replacement of spare parts, are provided as a matter of principle. The studies on printers therefore show that the indicator of spare parts availability is very relevant and should be included in the assessment of repairability.

4.4.4.1.5 Duration of availability

In addition to the question of which spare parts the manufacturers provide for which target groups, the manufacturers were also asked whether they guarantee the availability of spare parts for a certain period of time after the device has been placed on the market.

The particular importance of this question emerged in the course of the case studies, as the printer manufacturers repeatedly stated that the availability of spare parts depends, among other things, on the sales figures of different models. The availability of spare parts is therefore flexible in time, especially without a guarantee from the manufacturer, and can be adjusted by the manufacturer depending on what is happening on the market.

In line with these statements, one result of the case studies is that no printer manufacturer makes a statement on how long spare parts availability is guaranteed for any of the printer models examined. The policy of the manufacturers is homogeneous at this point.

If spare parts can no longer be obtained after just a few months or years, this severely limits the repairability of devices. Furthermore, if manufacturers do not make any statements or guarantees about the availability of spare parts, customers have no reliable information about whether a device they want to buy will even be supplied with spare parts in a few months. The results for the product group printers therefore show how important it is to include this possible indicator in an optimised scoring system.

4.4.4.1.6 Delivery time

Besides the availability of spare parts for different target groups, their delivery time in practice can also influence whether these parts are actually available for repairs. If there are spare parts that are theoretically available but can only be delivered after e. g., three months, their actual availability is hardly given. Such long delivery times can also influence the repair decisions of customers.

The delivery times for lay persons were requested from the printer manufacturers and authorised service partners for the selected spare parts. Therefore, the delivery times given here refer to the target groups of professional repairer and lay persons. It is possible that the delivery time for authorised service partners is shorter.

The delivery times for the selected inkjet printer spare parts are listed in Table 26 below. Here, "n/a." stands for "no availability" and is given, if the information is not given, because the spare part is not available. The abbreviation "n/s" stands for "no specified information" and is given, if the spare part is available but the information about the delivery time is not.

Table 26: Delivery time (in days) spare parts, inkjet printers

Spare part	MF3, IJP5	MF3, IJP6	MF1, IJP1	MF1, IJP2	MF2, IJP3	MF2, IJP4
Ink cartridges	1 – 2	1 – 2	1 – 2	1 – 2	1 – 2	1 – 2
Printer heads	1 – 2	10 – 12	1 – 2	n/a	1 - 2	1 – 2
Feed roller stacked sheet feeder	n/a	7 – 10	n/s	14	n/a	n/s
Internal power supply unit	n/a	7 – 10	n/s	14	n/a	n/a
Ink sponge	n/a	10 – 12	1 – 2	1 – 2	n/a	1 – 2

Source: Own depiction

For all printer models, the delivery time for ink cartridges as consumables is only 1-2 days. For other spare parts that are not consumables, it is considerably higher in almost all cases. The delivery time ranges from 7-10 days to 14 days. Overall, the delivery times for available spare parts other than consumables are up to two weeks. The manufacturers or authorised service partners did not provide information on delivery times in all cases.

The delivery times for the selected spare parts for laser printers are listed in Table 27 below.

Table 27: Delivery time (in days) spare parts, laser printers

Spare part	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Drum unit	1 – 2	1 – 2	1 – 2	1 – 2
Feed roller stacked sheet feeder	1 – 2	1 – 2	1 – 2	2

Spare part	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Transfer roller	12 – 14	n/a	n/s	56 – 70
Paper tray	14 – 20	12 – 14	n/a	3 – 4
Closing lid	12 – 14	12 – 14	n/a	14
Laser unit	14 – 20	12 – 14	n/a	3 – 4
Fixing unit	12 – 14	12 – 14	n/a	42
Internal supply unit	12 – 14	14	n/a	56 – 70
Drive motor for paper feed	n/a	12 – 14	n/a	2 – 14

Source: Own depiction

As with the inkjet printers, consumables (here: toner cartridges) are consistently available in 1-2 days. Furthermore, the feed rollers for the stacked sheet feeder can be obtained in up to 2 days. For the other selected spare parts, the delivery times are sometimes considerably longer. Many other parts have delivery times of around two weeks. For one printer model, delivery times of approximately eight to ten weeks are given for the transfer rollers and internal power supply unit. These are orders of magnitude for which spare parts are only theoretically available. For customers whose devices break down during this time, however, the parts cannot be obtained in a practical way.

Such results in the case study on printers illustrate why the possible indicator of delivery time of spare parts should be included in the assessment of repairability.

4.4.4.1.7 Costs

Just like very long delivery times for spare parts, very high costs for spare parts can also limit their actual availability to customers. For the case study, the costs of the selected spare parts were requested. The spare part prices are shown in Table 28 below.

Furthermore, in Table 28 below, the price of each spare part is given as a percentage of the RRP of the respective inkjet printer in order to estimate spare part prices in relation to the price of the device. (All prices shown are gross prices).

It should be noted that offer prices can be very variable. For example, the purchase prices for the printers for these case studies were sometimes clearly below the RRP. Therefore, the price of the spare parts in Table 28 is given as a percentage of the RRP.

Table 28: Costs (in €) spare parts, inkjet printers

Costs	MF3, IJP5	MF3, IJP6	MF1, IJP1	MF1, IJP2	MF2, IJP3	MF2, IJP4
RRP (€)	73.11	349.95	89.99	569.99	59.99	659.00
	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges	Ink cartridges

Costs	MF3, IJP5	MF3, IJP6	MF1, IJP1	MF1, IJP2	MF2, IJP3	MF2, IJP4
Costs €	18.00	9.99	9.49	9.99	14.99	95.9
% of RRP	24.62	2.85	10.55	1.74	24.99	14.57
	Print heads	Print heads	Print heads	Print heads	Print heads	Print heads
Costs €	18.00	31.55	66.62	n/a	14.99	84.08
% of RRP	24.62	9.02	74.03	n/a	24.99	12.76
	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder
Costs €	n/a	19.99	3.71	5.73	n/a	24.30
% of RRP	n/a	5.71	4.12	1.01	n/a	3.69
	Internal Power supply unit	Internal Power supply unit	Internal Power supply unit	Internal Power supply unit	Internal Power supply unit	Internal Power supply unit
Costs €	n/a	20.74	23.90	25.00	n/a	n/a
% of RRP	n/a	5.93	26.56	4.39	n/a	n/a
	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge	Ink sponge
Costs €	n/a	5.00	3.60	6.53	n/a	56.59
% of RRP	n/a	1.43	4.00	1.15	n/a	8.59

Source: Own depiction

For inkjet printers, the majority of spare parts prices as a percentage of the RRP vary between one and 25%. One outlier is the price of a print head, which is around 66 € in absolute terms. The spare parts price is thus around 75% of the UPV for the printer model. This is an order of magnitude at which a repair is highly unlikely to be carried out in practice, as one could almost purchase a new device for the price of the spare part.

The available feed rollers and the stack sheet feeder and ink sponges have comparatively somewhat lower spare parts prices (as a percentage of the RRP). Here the maximum is less than 9% of the RRP. For a high-priced model, this means an absolute price of around 56 € for an ink sponge.

The spare parts prices for the selected spare parts for laser printers are shown in Table 29 below, in absolute terms and as a percentage of the RRP.

Table 29: Costs (in €) spare parts, laser printers

Spare part	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
RRP (€)	249.00	629.00	130.00	480.00
	Drum unit	Drum unit	Drum unit	Drum unit
Costs €	75.00	89.00	56.49	97.98
% of RRP	30.12	14.15	43.45	20.41
	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder	Feed roller stacked sheet feeder
Costs €	9.75	1.76	23.31	14.04
% of RRP	3.92	0.28	17.93	2.93
	Transfer roller	Transfer roller	Transfer roller	Transfer roller
Costs €	29.07	n/a	23.31	19.75
% of RRP	11.67	n/a	17.93	4.11
	Paper tray	Paper tray	Paper tray	Paper tray
Costs €	6.78	64.23	n/a	109.22
% of RRP	2.72	10.21	n/a	22.75
	Closing lid	Closing lid	Closing lid	Closing lid
Costs €	36.38	91.09	n/a	552.68
% of RRP	14.61	14.48	n/a	115.14
Information	/	/	/	Only available together with laser unit
	Laser unit	Laser unit	Laser unit	Laser unit
Costs €	60.57	271.78	n/a	273.96
% of RRP	24.33	43.21	n/a	57.08
	Fixing unit	Fixing unit	Fixing unit	Fixing unit
Costs €	160.70	323.76	n/a	339.25

Spare part	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
% of RRP	64.54	51.47	n/a	79.68
	Internal power supply unit	Internal power supply unit	Internal power supply unit	Internal power supply unit
Costs €	215.00	238.16	n/a	192.75
% of RRP	86.35	37.86	n/a	40.16
	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed	Drive motor for paper feed
Costs €	n/a	49.08	n/a	28.60
% of RRP	n/a	7.80	n/a	5.96

Source: Own depiction

In the case of laser printers, there are some spare parts that can be obtained from all manufacturers at rather higher or lower costs. For example, the laser unit, fixing unit and internal power supply are comparatively expensive when they are available. Feed rollers, transfer rollers, paper trays and the drive motor for the paper transport are all comparatively cheaper. Prices here seem to depend on the spare parts and are lower for single parts than for units or assemblies.

There are several spare part prices that are more than 30% of the RRP. Six (out of 28) spare part prices are even higher than 50% of the RRP, in 3 cases they are around 80% or more than 80% of the RRP. One spare part can only be purchased as a unit with another part. The costs for this assembled part even exceed the RRP of the printer. Spare part prices in these dimensions hinder the repair of equipment, even if the spare parts are provided by the manufacturers.

The results for printers show that spare parts prices in dimensions that can prevent repairs occur in many cases and are therefore relevant in practice. According to the experience with this product group, spare parts costs should be included in an assessment of repairability as a matter of urgency. If necessary, it can be examined to what extent slightly higher costs could be justified for units or assemblies than for components.

4.4.4.2 Repair-relevant information

In this chapter the research results on the availability of information relevant to repairs and troubleshooting are briefly presented.

4.4.4.2.1 Information gathering

In order to research which repair-relevant information the manufacturers offer to which target groups, the following research steps were carried out:

- Research on the manufacturer's websites and evaluating the information.
- Written inquiries with the manufacturer and authorised service partners.
- Telephone inquiries with the manufacturer and authorised service partners.

- Search on third party internet sites and evaluation of the information to assess the importance of information materials.

The initial purpose of the search on the websites was to check which manuals and documentation as well as further information are offered there. The manuals and documentation found were then searched for information serving repairs.

Written and telephone inquiries were made in all cases with regard to repair manuals and circuit diagrams, as these were not publicly available. Telephone inquiries were carried out when written inquiries did not yield results.

In addition to obtaining information from the manufacturers, third-party websites were searched for repair-relevant information. These were evaluated in order to be able to assess the relevance of the information materials. For the presentation of results and the evaluation, these materials are not considered available, as they could not be obtained from the manufacturer.

In the following subchapters it is explained to what extent repair-relevant information on the printer models examined is provided by the manufacturers and whether there are differences between manufacturers and printer models. If relevant, it will be briefly shown whether the information proved to be necessary and helpful in the case studies and what challenges, if any, arise when this information is not available.

4.4.4.2.2 User manuals and set-up instructions

It was investigated which information is routinely provided by the manufacturers on websites. All manufacturers provide user manuals, quick guides and set-up instructions on their websites for all printer models investigated. (The term "user manual" is used below as a synonym for similar terms used by the manufacturers, such as online manual, user guide, instruction manual, etc.). The documents routinely provided were examined and it was found that these documents contain little to no repair-relevant information. One exception is the error code tables that are included in some user manuals.

Based on the experience with printers, the availability of "standard information materials" such as quick reference guides, set-up instructions and user manuals should not be included in the assessment of repairability, as they contain little repair-relevant information. They should only be checked to see if they contain the information that is considered relevant (exploded views, fault code tables, repair instructions, circuit diagrams).

4.4.4.2.3 Error code tables

The evaluation of the user manuals routinely provided for all printer models showed that error code tables are included in some of them. In addition, the evaluation of the manufacturers' websites showed that they make error code tables available online for some printer models. This includes lists or tables as well as search field entries. In many cases the error code tables are available both in the user manuals and in other places on the Internet.

The question "Is an error code table available, yes or no?" can be answered for each printer model examined. In the overall context of the case study, however, it became clear that answering this question in isolation does not represent the situation satisfactorily. Instead, the presence of error code tables must be seen in relation to the type of diagnostic interface. In the printer models considered, there are two cases of diagnostic interfaces that do not require additional hardware or software.

The first case is that error information is shown in plain language (here in writing) in the display. This diagnostic interface is not coded and the information output is understood directly. Accordingly, error code tables are not necessary or cannot exist for these printer models, as there are no codes that need to be decoded. Such interfaces are also referred to as intuitive. If there is to be an evaluation of the availability of error code tables, it must therefore be ensured that devices with non-coded diagnostic interfaces are not disadvantaged by this. (For a possible implementation see chapter 4.4.4.3).

The second case is that error information is output in coded form. In the examined printer models, flashing sequences of an LED on the printer are used for this purpose in all cases. For all printer models with such a coded interface, error code tables are also provided. An example of an entry in such a table is: X Flashing - The print head may be damaged.

The case of a coded interface occurs in two inkjet printers and one laser printer examined. The other printer models examined have intuitive diagnostic interfaces for which no error code tables are necessary. This case therefore dominates. An overview of error code tables and diagnostic interfaces is given in Table 30 below.

Table 30: Error code tables and diagnostic interfaces, printers

Technology	Model	Error code table	Diagnostic interface
Inkjet printer	Manufacturer 3, IJP5	Provided	Coded
Inkjet printer	Manufacturer 3, IJP6	Provided	Coded
Inkjet printer	Manufacturer 1, IJP1	Not necessary	Intuitive
Inkjet printer	Manufacturer1, IJP2	Not necessary	Intuitive
Inkjet printer	Manufacturer 2, IJP3	Not necessary	Intuitive
Inkjet printer	Manufacturer 2, IJP4	Not necessary	Intuitive
Laser printer	Manufacturer 3, LP3	Not necessary	Intuitive
Laser printer	Manufacturer 3, LP4	Not necessary	Intuitive
Laser printer	Manufacturer 2, LP1	Provided	Coded
Laser printer	Manufacturer 2, LP2	Not necessary	Intuitive

Source: Own depiction

With printers, errors are therefore usually indicated in writing on the display. Alternatively, error code tables are available. The scope of the available error code tables varies in some cases. Basic errors, such as empty consumables, but also challenges with paper jams, feeders and ink sponges are part of all error code tables. However, some error codes are not fully resolved. An example of such an entry is: X Flashing - A printer error has occurred that requires repair. Please contact our service centre.

The evaluation of the given error codes suggests that the error code tables can be used especially by lay persons for the first identification of a possible error and for the determination of the further procedure. They enable the first step towards a possible repair decision and, after the results on printers, belong to the repair-relevant information that should be included in an optimised scoring system for repairability.

4.4.4.2.4 Exploded views

After identifying a possible fault, in many cases it is a question of obtaining information on an affected spare part and, if necessary, obtaining it. The first prerequisite for obtaining spare parts is that they can be easily and clearly identified. This became impressively clear with the requests for spare parts (see chapter 4.4.4.1.4). In some cases, multiple telephone calls or written inquiries to the manufacturers were necessary to clarify which spare part should be ordered for which printer model or to verify whether a part offered for sale on the internet is compatible with the printer model investigated.

Clear differences were found between the three printer manufacturers in the ability to clearly identify spare parts. It made no difference whether the printer was an inkjet or laser printer.

Manufacturer 1 makes detailed exploded views of the models investigated available on its website through an authorised service partner. These are accompanied by unique part numbers and allow clear identification of the required spare parts. In this context, an exploded view is a graphical representation that shows both the appearance of individual spare parts and the location where they are installed in the unit. It does not necessarily have to be one complete drawing. It can happen that devices are shown in several layers and two or three illustrations together contain all spare parts and the location where they are installed.

A spare parts shop is provided on the web pages of manufacturer 2. After entering the serial numbers of the printer model under consideration, a list of spare parts is displayed, partly with the request to request them from authorised service partners. Although a number is given for the spare parts in the list, it remains unclear to what extent this is a unique part/article number. As already described, the answer to the inquiries to service partners was several times that parts cannot be delivered because no article number is known. Furthermore, neither drawings nor photos of the spare parts are provided. Without a graphic representation of parts and their location in the unit, it was sometimes difficult to find the right parts in the spare parts shop, because manufacturers sometimes use different designations / translations or parts can appear several times in the unit. An example of this are parts (such as rollers / rubbers) for sheet feeders. Exploded views were also not provided on request by the manufacturer or authorised sales partners. Clearly identifying and requesting the correct spare parts was therefore very time-consuming and involved multiple telephone and written inquiries for many parts.

No exploded views, no internet shop with a database or parts lists or comparable aids were provided by manufacturer 3 or its authorised service partner. The clear identification and request for the correct spare parts was most complex for the printer models of this manufacturer and involved multiple telephone calls and written inquiries for many parts.

According to the results on printers, an exploded view showing the spare parts and where they are installed is therefore considered very relevant for repair. The availability of an exploded view should be included in the assessment of repairability. The exploded view must be accompanied by a clear listing of part/article numbers or codes.

4.4.4.2.5 Repair manuals

Repair manuals were not found on any of the manufacturers' websites or in the manuals. All manufacturers were also asked whether they provide repair manuals for the three target groups: lay persons, professional repairer and authorised service partners. All three manufacturers agreed that repair manuals exist for all models and are only made available to authorised service partners. For the other two target groups, the repair manuals are not available for any of the models considered.

According to the statements of the repair company with which the practical investigations were carried out, repair manuals are very relevant. They are used in particular when new printer models come onto the market and repairers familiarise themselves with them.

Repair manuals could be obtained from third party suppliers for the majority of printer models in the case studies. As this is not an offer from the manufacturer, this possibility is not evaluated as an availability of repair manuals in the case studies and the application of the scoring system (see chapter 6).

However, their evaluation confirms the statements of the repair company. The repair manuals contain step-by-step instructions for repairing faults on appliances. They show the individual work steps that are to be carried out for the disassembly and reassembly of installed spare parts and the sequence intended by the manufacturer. This is particularly advantageous because the selected printer models are not very standardised, i. e., spare parts are not typically installed in the same places in the devices. The repair manual therefore helps to determine, for example, from which side a housing should be opened to reach the spare part. In addition, they convey, for example, the information on how devices should be oriented for certain work steps and which cable(s) must be disconnected, they enable the quick identification of fasteners and facilitate the correct disconnection of click connections. In some cases, the repair manuals also contain information on the number of fasteners or advice on suitable tools.

According to experience with printers, repair manuals can facilitate the repair of equipment and possibly lead to cost and time savings. Suitable instructions must contain recommended step sequences for individual repairs/disassembly. The availability of repair manuals should therefore be included in an optimised scoring system.

4.4.4.2.6 Circuit diagrams

Circuit diagrams were mentioned as helpful relevant information by the repair company with which the practical investigations were carried out.

The availability of circuit diagrams from printer manufacturers or authorised service partners is identical to the availability of repair manuals. According to the manufacturers, circuit diagrams are not made available to lay persons or professional repairer for any of the models considered. For authorised service partners, on the other hand, circuit diagrams are available for all models, according to the manufacturers.

Circuit diagrams are relevant during the repair of the device, both for fault location and identification, as well as for checking whether a fault could be remedied by a repair.

A circuit diagram shows the course of currents and voltages in a device. It shows for all installed parts what voltage must be present there during fault-free operation and what current the part must absorb. If the circuit diagram is available, repairers can measure at the connection terminals of each installed part whether the intended voltage is applied there. If this is not the case, the fault lies between the last part to which the intended voltage is applied and the first part to which it is not applied (example: a cable or capacitor in front of a motor is defective). If a part does not draw the intended current, the fault is in that part itself (example: a processor is defective and should be replaced). The information contained in circuit diagrams is not so much for the initial repair decision, but is helpful during the repair that has been started. This makes them particularly important for the target groups of professional repairer and authorised service partners. Their availability should be included in an assessment of repairability.

The possibilities of taking the repair-relevant information mentioned in this sub-chapter into account in a rating system are discussed in chapter 5.2.6.

4.4.4.3 Diagnostic interfaces

This chapter describes the research and results on interfaces. The types of diagnostic interfaces were gathered from the user manuals and from the manufacturers' websites.

4.4.4.3.1 Types of diagnostic interfaces

Diagnostic interfaces are used to identify errors that have occurred and are therefore relevant for repairs, especially initial repair decisions. The types of diagnostic interfaces in the considered printer models are already described in detail Table 30. Coded diagnostic interfaces occur three times and intuitive diagnostic interfaces seven times. It is important in the evaluation, as explained there, that diagnostic tables and error code tables are considered together. A possible implementation in an evaluation system is shown in chapter 5.2.7.

In addition to these user interfaces, all printer models have a USB port as a data interface. These are publicly accessible interfaces that can be accessed with the help of the driver.

According to experience with printers, diagnostic interfaces and error code tables should be evaluated in relation to each other. According to the experience with printers, an evaluation of interfaces should at least map intuitive and coded interface as well as public hardware interfaces.

4.4.4.3.2 Software and firmware

This chapter describes whether and how manufacturers provide software relevant to the operation and repair of printers.

4.4.4.3.3 Information gathering

In order to research which software the manufacturers offer to which target groups, three research steps were carried out:

- Research on website of manufacturers and authorised service partners.
- Written inquiries with manufacturers and authorised service partners.
- Telephone inquiries with manufacturers and authorised service partners.

The availability of the software was primarily researched on the manufacturers' websites. Steps two and three were carried out if software was not already available. Furthermore, all manufacturers were asked whether the software is available for a guaranteed period of time.

4.4.4.3.4 Availability of software

Relevant software in relation to printers are printer drivers. On the one hand, they are needed to operate the devices and on the other hand, they are used by repairers to check the success of the repair.

The research has shown that many printer drivers can be publicly downloaded from the manufacturers' websites. Drivers that are not available there could not be obtained from the manufacturers or authorised service partners. Some respondents stated that these drivers do not exist, others made no statement on this.

In Table 31 the availability of drivers for the inkjet printers is shown.

Table 31: Availability of printer drivers, inkjet printers

System	MF3, IJP5	MF3, IJP6	MF1, IJP1	MF1, IJP2	MF2, IJP3	MF2, IJP4
Windows 10	Available	Available	Available	Available	Available	Available
Windows 8	Available	Available	Available	Available	Available	Available

System	MF3, IJP5	MF3, IJP6	MF1, IJP1	MF1, IJP2	MF2, IJP3	MF2, IJP4
Windows 7	Available	Available	Available	Available	Available	Available
Windows older	Available	Available	Available	Available	Not Available	Not Available
macOS 10.15	Available	Available	Not Available	Available	Available	Available
macOS 10.14	Available	Available	Not Available	Available	Available	Available
macOS 10.13	Available	Available	Available	Available	Available	Available
macOS older	Available	Available	Available	Available	Available	Available
Linux	Not Available	Available	Not Available	Available	Not Available	Not Available

Source: Own depiction

Drivers for current Windows operating systems are provided for all printer models. Drivers for older Apple operating systems can also be used for all devices. For one device, no drivers are available for newer versions of the Apple operating system. A Linux driver is only available for two of the four models.

In the following Table 32 a summary of the availability of drivers for laser printers is given.

Table 32: Availability of printer drivers, laser printers

System	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2
Windows 10	Available	Available	Available	Available
Windows 8	Available	Available	Available	Available
Windows 7	Available	Available	Available	Available
Windows older	Not Available	Not Available	Not Available	Not Available
macOS 10.15	Available	Available	Available	Available
macOS 10.14	Available	Available	Available	Available
macOS 10.13	Available	Available	Available	Available
macOS older	Available	Available	Available	Available
Linux	Available	Available	Not Available	Not Available

Source: Own depiction

For all printer models there is a driver available that can be used for current Windows operating systems. Only systems older than Windows 7 are not supported by any manufacturer. A Linux driver is offered for two of the four models examined.

When inkjet and laser printers are considered together, the availability of Windows and macOS (Apple) drivers is good. Linux drivers are not offered by one manufacturer for any of its models. For the other two manufacturers, this depends on the model. Some respondents commented on the phone that Linux drivers are not provided because there are too many versions of this operating system, others did not comment.

The software provided by the manufacturers can be obtained free of charge in all cases. Delivery times are not relevant because the software is downloaded.

In addition to general availability, the manufacturers were asked whether they promise the availability of updated drivers for future operating systems for a defined period of time. This is not the case with any manufacturer. This is in line with the results on the supply of spare parts, for which no printer manufacturer guarantees a period of availability either. When asked about drivers, some respondents also stated that the decision to make them available is flexibly adjusted depending on the sales figures of models.

The general availability of drivers at the time of the case studies was therefore good overall. However, there are no guaranteed periods for which new operating systems are guaranteed to be covered. The aspect of guaranteed availability of drivers for operating systems that may not appear until after the original sale of the printer model is particularly relevant for this indicator. It can happen that otherwise functional printers can no longer be operated or repaired if users buy new computers with current operating systems on which these printers are to be operated. Furthermore, this can happen when users (have to) upgrade to newer operating systems for their computers. Due to the regular new versions of operating systems, such cases occur regularly in practice. In contrast, spare parts only need to be replaced if a fault occurs in the installed parts. A guaranteed update period for drivers is therefore particularly important for printers and should be prioritised for an evaluation system over the pure availability of drivers. According to the results for printers, costs and delivery times are not relevant for printers.

4.4.4.3.5 Availability of firmware

Just like the availability of drivers, the availability of firmware was also checked. Firmware here refers to the operating system of the printers.

The research showed that all printer manufacturers make firmware available for all printer models examined that are operated on devices with Windows or Apple operating systems. In contrast, no firmware is provided for Linux. It should be noted here that firmware only needs to be updated if errors or security gaps occur. Updating firmware is of little relevance to the target group of lay persons.

For one manufacturer, the firmware can be downloaded from the website. The other manufacturers state that the firmware is available from authorised service partners and is made available to professional repairer free of charge upon request via a download link.

However, as with software, no manufacturer guarantees a period of time in which firmware will be updated and made available. If firmware is included in an evaluation system, this aspect should be evaluated because the availability itself is given for the relevant target groups and no costs or delivery times occur.

4.4.4.4 Restoring the factory settings

This chapter presents the results of the research on restoring the factory settings (reset). The options for restoring the factory settings were researched on the manufacturers' websites and in the user manuals. Since information on restoring the factory settings could be found for all devices, no further research steps were necessary.

4.4.4.4.1 Options to restore the factory settings

Factory reset may be necessary to return devices to a state before a fault occurred. In addition, a reset, including a password reset, can be useful when devices are passed on to new users.

All printer models examined can be reset to their factory settings. For all models, this reset can be carried out by the users (lay persons). So-called “service resets”, which can only be carried out by manufacturers or authorised service partners, are not necessary. It is possible that this service is offered, but since simpler options are available, this is not relevant for an evaluation of the reset options.

There are two ways in which users can reset printers to factory settings. In the first case, the reset is performed on the printer without any additional tools and is referred to as an “integrated reset”. In the case of the printer models examined, this is possible by entering key sequences or entries on the display. In the second case, additional software is used to perform the reset. This case is called “external reset”. In the printer models examined, external resets are performed via the driver on the computer to which the printer is connected.

External resets are necessary for two printers examined, one inkjet and one laser. In the other printer models examined, the option of resetting the factory settings is integrated in the device. So this case dominates. An overview of the options for performing a reset is given in Table 33 below.

Table 33: Options to reset printers

Technology	Model	Reset option
Inkjet printer	Manufacturer 3, IJP5	External
Inkjet printer	Manufacturer 3, IJP6	Integrated
Inkjet printer	Manufacturer 1, IJP1	Integrated
Inkjet printer	Manufacturer 1, IJP2	Integrated
Inkjet printer	Manufacturer 2, IJP3	Integrated
Inkjet printer	Manufacturer 2, IJP4	Integrated
Laser printer	Manufacturer 3, LP3	Integrated
Laser printer	Manufacturer 3, LP4	Integrated
Laser printer	Manufacturer 2, LP1	External
Laser printer	Manufacturer 2, LP2	Integrated

Source: Own depiction

The inability to reset a device to its factory settings would prevent comparatively simple repairs and limit the transfer of devices to new users. The indicator should be considered in an optimised scoring system.

4.5 Tumble dryers

In the following chapter the selection of devices and priority parts as well as the results of the practical investigations and research are described.

4.5.1 Selected devices

Once the product groups to be investigated had been agreed, it was determined together with the client which appliances were to be investigated in the case studies. Since the project focuses on current product policy instruments, e. g., for regulating market access, dryers were selected that were being sold in Germany at the time of the investigations. In addition, the focus of the case studies was on devices that can also be used in private households.

When selecting the dryers, the market-leading manufacturers were taken into account in order to cover as large a proportion as possible of the devices placed on the market. In addition, manufacturers from non-European countries were included in order to investigate whether, and if so which, differences could be shown with regard to repairability. Dryers with the relevant technical principles of exhaust air dryers, condense dryers and heat pump dryers were examined. In some cases, different components are installed in dryers of the three technologies.

A focus was placed on heat pump dryers, as a forward-looking technology. Where possible, one appliance from each manufacturer was selected for each technology in the lower and medium quality / or price segments. This principle was deviated from if a manufacturer did not offer a dryer on the market in the respective market segment. When selecting the dryer models, the devices that were indicated as bestsellers by the major online platforms were taken into account.

In Table 34 an overview of the selected devices per manufacturer and technology is given.

Table 34: Dryers selected for the case studies

Technology	Manufacturer	Model	RRP (€)
Exhaust air dryer	Manufacturer 1	EAD1	589.00
Exhaust air dryer	Manufacturer 4	EAD2	778.86
Condense dryer	Manufacturer 6	CDD2	439.00
Condense dryer	Manufacturer 6	CDD3	467.01
Condense dryer	Manufacturer 1	CDD1	679.00
Heat pump dryer	Manufacturer 6	HPD9	1049.00
Heat pump dryer	Manufacturer 6	HPD10	648.00
Heat pump dryer	Manufacturer 1	HPD1	889.00
Heat pump dryer	Manufacturer 1	HPD2	999.00
Heat pump dryer	Manufacturer 2	HPD3	799.00
Heat pump dryer	Manufacturer 3	HPD4	549.00
Heat pump dryer	Manufacturer 4	HPD5	955.00
Heat pump dryer	Manufacturer 4	HPD6	869.00
Heat pump dryer	Manufacturer 5	HPD7	681.00
Heat pump dryer	Manufacturer 5	HPD8	1022.55

Source: Own depiction

4.5.2 Priority parts

As with the printers, the following sources of information were used to select the priority parts for the practical investigations:

- offers of spare parts in online stores,
- literature review,
- brief survey among selected repairers.

The results were then coordinated with the experts from UBA and the priority parts listed in Table 35 were determined.

Table 35: Selected priority parts, dryers

Exhaust air dryer	Condense dryer	Heat pump dryer
Felt pads drum	Felt pads drum	Felt pads drum
Main board	Main board	Main board
Heating	Heating	Fan / blower
Fan / blower	Fan / blower	Motor
Motor	Motor	Motor condensers
Motor condensers	Motor condensers	Motor converter / control unit
Motor converter / control unit	Motor converter / control unit	Pump (condensate)
Relays	Pump (condensate)	Relays
Belt	Relays	Belt
Sensors	Belt	Sensors
Tensioner pulley	Sensors	Tensioner pulley
Drum bearing	Tensioner pulley	Drum bearing
Door lock	Drum bearing	Door lock
	Door lock	Heat pump
		Heat exchanger

Source: Own depiction

4.5.3 Practical investigations

This subsection summarizes the key data on the practical investigations in table format and key findings are presented.

First of all, it can be stated that relays were not present in any of the dryer models examined. They are therefore not considered any further in the following evaluation.

For future studies, it can be assumed that relays do not play a role in newly marketed devices. Their mention by the repairers surveyed could be due to the fact that the respondents work on older devices in their practice in which these parts may be present.

4.5.3.1 Exhaust air dryers and condense dryers

For the exhaust air dryers and condense dryers studied, the data on the remaining priority parts are shown in Table 36. If parts are not present in a dryer model, "n/p". was indicated for "not present".

Table 36: Indicators practical investigations, exhaust air dryers and condense dryers

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
	Pump	Pump	Pump	Pump	Pump
Number of fasteners	n/p	n/p	n/p	10	31
Thereof screws	n/p	n/p	n/p	1	16
Number of tools	n/p	n/p	n/p	3	5
Number of uses of tools	n/p	n/p	n/p	2	11
Number of tool changes	n/p	n/p	n/p	1	8
Number of steps	n/p	n/p	n/p	10	23
Disassembly time (hh:mm:ss)	n/p	n/p	n/p	00:03:00	00:13:00
	Drum bearing	Drum bearing	Drum bearing	Drum bearing	Drum bearing
Number of fasteners	6	12	26	26	18
Thereof screws	2	9	23	23	14
Number of tools	2	3	2	2	4
Number of uses of tools	3	5	6	6	9
Number of tool changes	2	3	3	3	5
Number of steps	6	11	11	11	15
Disassembly time (hh:mm:ss)	00:01:30	00:08:30	00:08:00	00:08:00	00:08:00
	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter
Number of fasteners	0	0	0	0	0
Thereof screws	0	0	0	0	0

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of tools	0	0	0	0	0
Number of uses of tools	0	0	0	0	0
Number of tool changes	0	0	0	0	0
Number of steps	2	2	2	2	3
Disassembly time (hh:mm:ss)	00:00:10	00:00:05	00:00:05	00:00:05	00:00:10
	Seal	Seal	Seal	Seal	Seal
Number of fasteners	0	10	0	0	0
Thereof screws	0	10	0	0	0
Number of tools	0	2	0	0	0
Number of uses of tools	0	5	0	0	0
Number of tool changes	0	2	0	0	0
Number of steps	0	11	0	0	0
Disassembly time (hh:mm:ss)	00:00:10	00:07:00	00:00:10	00:00:10	00:00:10
	Door	Door	Door	Door	Door
Number of fasteners	2	2	2	2	2
Thereof screws	2	2	2	2	2
Number of tools	1	1	1	1	1
Number of uses of tools	1	1	1	1	1
Number of tool changes	0	0	0	0	0
Number of steps	3	3	3	3	3
Disassembly time (hh:mm:ss)	00:01:00	00:01:30	00:00:30	00:00:30	00:01:00

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
	Hinge	Hinge	Hinge	Hinge	Hinge
Number of fasteners	2	5	21	21	2
Thereof screws	2	5	5	5	2
Number of tools	1	2	2	2	1
Number of uses of tools	1	4	3	3	1
Number of tool changes	0	1	1	1	0
Number of steps	3	10	7	7	3
Disassembly time (hh:mm:ss)	00:01:00	00:05:00	00:04:00	00:04:00	00:01:00
	Locking nose	Locking nose	Locking nose	Locking nose	Locking nose
Number of fasteners	2	5	22	22	2
Thereof screws	2	5	5	5	2
Number of tools	1	1	2	2	1
Number of uses of tools	1	3	3	3	1
Number of tool changes	0	0	1	1	0
Number of steps	3	6	8	8	3
Disassembly time (hh:mm:ss)	00:01:00	00:03:00	00:04:30	00:04:00	00:01:00
	Door locking nose port	Door locking nose port	Door locking nose port	Door locking nose port	Door locking nose port
Number of fasteners	31	30	61	63	2
Thereof screws	17	17	32	33	2
Number of tools	4	4	2	2	1
Number of uses of tools	12	11	11	11	1

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of tool changes	10	9	1	1	0
Number of steps	27	26	43	44	4
Disassembly time (hh:mm:ss)	00:13:00	00:12:00	00:18:00	00:19:00	00:01:00
	Handle	Handle	Handle	Handle	Handle
Number of fasteners	2	14	23	23	2
Thereof screws	2	13	5	5	2
Number of tools	1	3	2	2	1
Number of uses of tools	1	4	3	3	1
Number of tool changes	0	2	1	1	0
Number of steps	3	8	6	6	3
Disassembly time (hh:mm:ss)	00:01:00	00:08:30	00:04:30	00:04:00	00:01:00
	Filter	Filter	Filter	Filter	Filter
Number of fasteners	n/p	0	0	0	0
Thereof screws	n/p	0	0	0	0
Number of tools	n/p	0	0	0	0
Number of uses of tools	n/p	0	0	0	0
Number of tool changes	n/p	0	0	0	0
Number of steps	n/p	4	3	3	3
Disassembly time (hh:mm:ss)	n/p	00:00:30	00:00:10	00:00:10	00:00:15
	Control board	Control board	Control board	Control board	Control board
Number of fasteners	21	13	27	24	23
Thereof screws	3	4	6	7	5
Number of tools	3	3	2	2	4

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of uses of tools	6	6	4	4	4
Number of tool changes	5	5	1	1	3
Number of steps	14	14	13	12	12
Disassembly time (hh:mm:ss)	00:06:00	00:07:00	00:07:00	00:07:00	00:06:00
	Main board	Main board	Main board	Main board	Main board
Number of fasteners	40	13	27	24	42
Thereof screws	11	4	6	7	15
Number of tools	5	3	2	2	4
Number of uses of tools	11	6	4	4	7
Number of tool changes	11	5	1	1	6
Number of steps	23	14	13	12	19
Disassembly time (hh:mm:ss)	00:11:00	00:07:00	00:07:00	00:07:00	00:09:00
	Heating	Heating	Heating	Heating	Heating
Number of fasteners	39	16	31	31	32
Thereof screws	24	9	22	22	27
Number of tools	3	4	2	2	3
Number of uses of tools	12	8	4	4	8
Number of tool changes	10	6	1	1	4
Number of steps	26	15	13	13	19
Disassembly time (hh:mm:ss)	00:15:00	00:08:00	00:08:00	00:08:00	00:11:00
	Motor capacitors	Motor capacitors	Motor capacitors	Motor capacitors	Motor capacitors
Number of fasteners	26	25	32	33	26

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Thereof screws	13	22	27	18	16
Number of tools	3	4	3	3	5
Number of uses of tools	9	11	9	9	9
Number of tool changes	8	7	3	3	7
Number of steps	20	18	21	22	17
Disassembly time (hh:mm:ss)	00:09:00	00:13:00	00:11:00	00:11:00	00:08:00
	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt
Number of fasteners	61	50	72	76	73
Thereof screws	41	36	49	52	47
Number of tools	7	5	2	2	4
Number of uses of tools	22	17	14	15	23
Number of tool changes	19	12	6	6	17
Number of steps	50	42	41	46	55
Disassembly time (hh:mm:ss)	00:24:00	00:21:00	00:21:00	00:24:00	00:24:00
	Tensioner pulley belt	Tensioner pulley belt	Tensioner pulley belt	Tensioner pulley belt	Tensioner pulley belt
Number of fasteners	n/p	22	75	87	n/p
Thereof screws	n/p	22	51	54	n/p
Number of tools	n/p	2	4	4	n/p
Number of uses of tools	n/p	9	18	19	n/p
Number of tool changes	n/p	5	9	9	n/p
Number of steps	n/p	17	54	59	n/p
Disassembly time (hh:mm:ss)	n/p	00:12:00	00:28:00	00:31:00	n/p

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
	Tensioner pulley	Tensioner pulley	Tensioner pulley	Tensioner pulley	Tensioner pulley
Number of fasteners	67	n/p	76	88	78
Thereof screws	43	n/p	51	54	47
Number of tools	7	n/p	4	4	6
Number of uses of tools	24	n/p	20	20	27
Number of tool changes	19	n/p	10	10	20
Number of steps	54	n/p	56	61	62
Disassembly time (hh:mm:ss)	00:25:00	n/p	00:28:00	00:31:00	00:28:00
	Motor	Motor	Motor	Motor	Motor
Number of fasteners	67	69	77	89	79
Thereof screws	43	48	51	54	47
Number of tools	7	7	4	4	7
Number of uses of tools	24	26	20	21	29
Number of tool changes	19	18	11	11	22
Number of steps	54	62	58	63	65
Disassembly time (hh:mm:ss)	00:25:00	00:34:00	00:29:00	00:32:00	00:29:00
	Level sensor	Level sensor	Level sensor	Level sensor	Level sensor
Number of fasteners	n/p	n/p	6	7	31
Thereof screws	n/p	n/p	0	1	15
Number of tools	n/p	n/p	1	2	5
Number of uses of tools	n/p	n/p	1	2	11
Number of tool changes	n/p	n/p	0	1	8

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of steps	n/p	n/p	6	7	23
Disassembly time (hh:mm:ss)	n/p	n/p	00:02:00	00:02:00	00:13:00
	Humidity sensor	Humidity sensor	Humidity sensor	Humidity sensor	Humidity sensor
Number of fasteners	34	5	6	6	4
Thereof screws	18	2	4	4	2
Number of tools	4	2	2	2	1
Number of uses of tools	13	4	2	2	1
Number of tool changes	11	3	1	1	0
Number of steps	30	8	5	5	7
Disassembly time (hh:mm:ss)	00:14:00	00:04:00	00:03:00	00:03:00	00:03:00
	Door lock sensor	Door lock sensor	Door lock sensor	Door lock sensor	Door lock sensor
Number of fasteners	31	30	61	63	40
Thereof screws	17	17	32	33	19
Number of tools	4	4	2	2	4
Number of uses of tools	12	11	11	11	12
Number of tool changes	10	8	1	1	8
Number of steps	27	26	43	44	31
Disassembly time (hh:mm:ss)	00:13:00	00:12:00	00:18:00	00:19:00	00:13:00
	Process air sensor	Process air sensor	Process air sensor	Process air sensor	Process air sensor
Number of fasteners	n/p	16	5	5	24
Thereof screws	n/p	15	1	1	14
Number of tools	n/p	2	2	1	3

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of uses of tools	n/p	8	2	1	7
Number of tool changes	n/p	5	1	0	5
Number of steps	n/p	15	6	6	16
Disassembly time (hh:mm:ss)	n/p	10:00	00:01:30	00:02:00	00:07:00
	Heating temperature sensor	Heating temperature sensor	Heating temperature sensor	Heating temperature sensor	Heating temperature sensor
Number of fasteners	39	10	22	22	34
Thereof screws	25	7	18	18	27
Number of tools	4	2	2	2	3
Number of uses of tools	13	3	2	2	9
Number of tool changes	11	1	1	1	4
Number of steps	30	7	5	5	23
Disassembly time (hh:mm:ss)	00:17:00	00:04:00	00:04:00	00:04:00	00:14:00
	Heating thermal fuse 1	Heating thermal fuse 1	Heating thermal fuse 1	Heating thermal fuse 1	Heating thermal fuse 1
Number of fasteners	16	11	22	22	23
Thereof screws	12	7	18	18	14
Number of tools	3	3	2	2	3
Number of uses of tools	6	4	2	2	3
Number of tool changes	3	2	1	1	2
Number of steps	6	7	5	5	7
Disassembly time (hh:mm:ss)	00:03:00	00:04:30	00:04:00	00:04:00	00:04:00
	Heating thermal fuse 2	Heating thermal fuse 2	Heating thermal fuse 2	Heating thermal fuse 2	Heating thermal fuse 2

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Number of fasteners	16	n/p	n/p	n/p	n/p
Thereof screws	12	n/p	n/p	n/p	n/p
Number of tools	3	n/p	n/p	n/p	n/p
Number of uses of tools	6	n/p	n/p	n/p	n/p
Number of tool changes	3	n/p	n/p	n/p	n/p
Number of steps	6	n/p	n/p	n/p	n/p
Disassembly time (hh:mm:ss)	00:04:00	n/p	n/p	n/p	n/p
	Rear drum seal	Rear drum seal	Rear drum seal	Rear drum seal	Rear drum seal
Number of fasteners	61	62	78	77	64
Thereof screws	41	45	55	56	44
Number of tools	7	6	2	2	4
Number of uses of tools	22	22	15	15	21
Number of tool changes	17	16	6	6	15
Number of steps	48	54	41	46	47
Disassembly time (hh:mm:ss)	00:24:00	00:31:00	00:22:00	00:24:00	00:23:00
	Front drum seal	Front drum seal	Front drum seal	Front drum seal	Front drum seal
Number of fasteners	61	41	72	76	64
Thereof screws	41	27	49	52	44
Number of tools	7	5	2	2	4
Number of uses of tools	23	17	14	16	21
Number of tool changes	18	12	7	7	15
Number of steps	51	40	43	48	52

	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Disassembly time (hh:mm:ss)	00:25:00	00:21:00	00:24:00	00:25:00	00:25:00
	Blower	Blower	Blower	Blower	Blower
Number of fasteners	38	42	19	19	40
Thereof screws	23	28	18	18	29
Number of tools	3	5	2	2	5
Number of uses of tools	12	17	2	2	11
Number of tool changes	9	11	1	1	9
Number of steps	23	40	4	4	21
Disassembly time (hh:mm:ss)	00:11:00	00:19:00	00:04:00	00:04:00	00:10:00
	Fan	Fan	Fan	Fan	Fan
Number of fasteners	n/p	n/p	76	88	79
Thereof screws	n/p	n/p	51	54	47
Number of tools	n/p	n/p	4	3	7
Number of uses of tools	n/p	n/p	19	20	29
Number of tool changes	n/p	n/p	10	10	22
Number of steps	n/p	n/p	55	60	65
Disassembly time (hh:mm:ss)	n/p	n/p	00:29:00	00:31:00	00:29:00
Specifics	There were three cable ties used as non-reusable fasteners that did not note-worthy affect disassembly.	There were three cable ties used as non-reusable fasteners that did not note-worthy affect disassembly.	/	/	/

Source: Own depiction

When looking at exhaust air dryers and condense dryers, it is noticeable that some selected priority parts, e. g., the tensioner pulley, are not present in all models due to the design. In addition, it is noticeable that many door parts can only be replaced as an assembly. The design of the doors is therefore difficult to compare. Door parts and other priority parts not found in all of the models are therefore excluded from a comparative analysis. The entire door, on the other hand, is included in the comparison.

As a rough guide for comparison between dryers, the indicators considered can be summed up for several priority parts. It makes sense to do this for priority parts that occur in all dryer models. For the exhaust air dryers these are:

- drum bearing,
- door,
- door locking nose port,
- control board,
- main board,
- heating,
- condenser,
- drum belt,
- motor,
- humidity sensors,
- door lock sensor,
- heating temperature sensor,
- heating thermal fuse,
- rear drum seal,
- front drum seal,
- blower.

For these priority parts, the totals of the indicators are shown in Table 37.

Table 37: Total indicators for comparable priority parts, exhaust air dryer

Totals	Manufacturer 1, EAD1	Manufacturer 4, EAD2
Total fasteners	573	431
Total screws	333	284
Total tools	67	61
Total uses of tools	201	169
Total tool changes	163	118
Total steps	438	387

Totals	Manufacturer 1, EAD1	Manufacturer 4, EAD2
Total disassembly time	03:32:30	03:27:30
RRP (€)	589.00	778.86

Source: Own depiction

When looking at the disassembly times, it can be seen that the total for dryer model EAD1 from manufacturer 1 and dryer model EAD2 from manufacturer 4 only deviates by 5 minutes. It does not show that a larger number of steps or fastening element does not necessarily lead to a higher disassembly time. This also applies to the other indicators. The installation situation of some priority parts could be relevant. For example, the blower in the dryer model EAD2 from manufacturer 4 is installed on the inside and is not accessible from the rear. When interpreting the results, it must be considered that only two devices are being investigated. It does not make sense to investigate mathematical relationships for these two devices.

For the condense dryers, the indicators of the following priority parts can be summed up for a simplified comparison:

- drum bearing,
- door,
- door locking nose port,
- filter,
- control board,
- main board,
- heating,
- condensers,
- drum belt,
- motor,
- tensioner pulley,
- fill level sensor,
- humidity sensors,
- door lock sensor,
- process air sensor,
- heating temperature sensor,
- heating thermal fuse,
- rear drum seal,
- front drum seal,

- blower and
- fan.

For these priority parts, the totals of the indicators are shown in Table 38.

Table 38: Total indicators for comparable priority parts, condense dryers

Totals	MF6, CDD2	MF6, CDD3	MF1, CDD1
Total fasteners	798	841	778
Total screws	515	527	477
Total tools	45	44	78
Total tool inserts	163	168	243
Total tool change	66	66	172
Total steps	488	520	566
Total disassembly time	04:09:10	04:25:40	04:26:15
RRP (€)	439.00	467.01	679.00

Source: Own depiction

The total of the disassembly times is relatively similar for the three condense dryers. For the CDD2 model from manufacturer 6, the total is approx. 4 hours and 10 minutes. The total of the other two models is about 15 minutes higher and very similar. The dryer with the highest or lowest total of the steps, also has the highest or lowest total of the disassembly time. This does not apply to the total of the fastening elements and the total of the disassembly time. Again, it must be noted that only a small number of devices were examined. A mathematical investigation of the correlations is therefore not carried out.

A relatively high number of tools, uses of tools and tool changes is noticeable in the CDD1 model from manufacturer 1. This may be due to the fact that Torx screws of different sizes (primarily 15 and 20) are installed in all the dryer models from manufacturer 1 examined. With the counting method used, this also leads to a somewhat higher number of steps. However, the practical investigations have shown that the different screw sizes and the resulting tool changes do not considerably increase the disassembly times. It should be noted that in this case it is usually a matter of changing between only two tools, which can be kept in hand if necessary. It cannot be ruled out that an even greater variety of screws and tools would have a negative effect on disassembly times.

4.5.3.2 Heat pump dryers

For the examined heat pump dryers, the data on the priority parts are shown in Table 39. If components are not present in a dryer model, “n/p” was given for “not present”.

Table 39: Indicators priority parts, heat pump dryers

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump
Fasteners	10	11	5	5	28	16	53	53	7	7
Thereof screws	1	1	0	0	18	4	41	41	2	2
Tools	2	3	2	2	2	3	5	5	2	2
Uses of tools	2	3	2	2	6	4	13	13	2	2
Tool changes	1	2	1	1	1	3	7	7	1	1
Steps	10	10	6	6	21	12	40	40	8	8
Time (hh: mm:ss)	00:03: 00	00:03: 00	00:03: 00	00:02: 30	00:13: 00	00:05: 00	00:27: 00	00:27: 00	00:04: 00	00:04: 00
	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing	Bear-ing
Fasteners	25	21	23	25	28	19	50	50	55	54
Thereof screws	24	20	23	25	28	15	41	41	45	49
Tools	2	2	4	3	1	3	6	6	3	3
Uses of tools	5	5	6	5	5	5	14	14	11	13
Tool changes	3	3	5	3	0	2	8	8	4	4
Steps	13	9	10	10	12	8	36	36	27	28
Time (hh: mm:ss)	00:09: 00	00:05: 00	00:05: 00	00:05: 00	00:08: 00	00:03: 30	00:25: 00	00:25: 00	00:20: 00	00:20: 00
	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter	Lint filter
Fasteners	0	0	0	0	0	0	0	0	0	0
Thereof screws	0	0	0	0	0	0	0	0	0	0
Tools	0	0	0	0	0	0	0	0	0	0

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Uses of tools	0	0	0	0	0	0	0	0	0	0
Tool changes	0	0	0	0	0	0	0	0	0	0
Steps	2	2	3	3	2	2	3	3	2	2
Time (hh: mm:ss)	00:00: 10	00:00: 05	00:00: 10	00:00: 10	00:00: 05	00:00: 10	00:00: 15	00:00: 15	00:00: 10	00:00: 10
	Seal	Seal	Seal	Seal	Seal	Seal	Seal	Seal	Seal	Seal
Fasteners	0	0	0	2	0	0	0	0	0	0
Thereof screws	0	0	0	2	0	0	0	0	0	0
Tools	0	0	0	1	0	0	0	0	0	0
Uses of tools	0	0	0	1	0	0	0	0	0	0
Tool changes	0	0	0	0	0	0	0	0	0	0
Steps	2	2	2	3	2	2	2	2	2	2
Time (hh: mm:ss)	00:00: 10	00:00: 10	00:00: 10	00:01: 20	00:00: 10	00:00: 10	00:00: 10	00:00: 10	00:00: 10	00:00: 10
	Coun-ter seal									
Fasteners	40	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Thereof screws	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Tools	1	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Uses of tools	4	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Tool changes	0	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Steps	12	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Time (hh: mm:ss)	00:11: 00	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
	Door	Door	Door	Door	Door	Door	Door	Door	Door	Door
Fasteners	2	2	2	2	2	2	2	2	2	2

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Thereof screws	2	2	2	2	2	2	2	2	2	2
Tools	1	1	1	1	1	1	1	1	1	2
Uses of tools	1	1	1	1	1	1	1	1	1	2
Tool changes	0	0	0	0	0	0	0	0	0	1
Steps	3	3	3	3	3	3	3	3	3	3
Time (hh:mm:ss)	00:00:30	00:00:30	00:01:00	00:01:20	00:01:00	00:01:00	00:01:30	00:00:30	00:01:00	00:02:00
	Hinge	Hinge	Hinge	Hinge	Hinge	Hinge	Hinge	Hinge	Hinge	Hinge
Fasteners	12	27	2	2	15	16	14	14	26	27
Thereof screws	12	5	2	2	13	13	13	13	14	15
Tools	1	2	1	1	1	1	3	3	1	3
Uses of tools	4	3	1	1	2	2	4	4	2	6
Tool changes	0	1	0	0	0	0	2	2	0	3
Steps	11	7	3	3	7	7	9	9	6	11
Time (hh:mm:ss)	00:05:00	00:05:00	00:01:00	00:01:20	00:04:00	00:04:30	00:09:00	00:09:00	00:05:00	00:09:00
	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose	Lock-ing nose
Fasteners	9	28	2	2	15	14	14	14	2	2
Thereof screws	8	5	2	2	13	13	13	13	2	2
Tools	2	2	1	1	1	1	3	3	1	1
Uses of tools	4	3	1	1	2	2	4	4	1	1
Tool changes	1	1	0	0	0	0	2	2	0	0
Steps	10	8	3	3	7	6	9	9	3	3

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Time (hh: mm:ss)	00:04: 30	00:05: 00	00:01: 00	00:01: 20	00:04: 00	00:04: 00	00:09: 00	00:09: 00	00:00: 30	00:00: 30
	DLNP	DLNP	DLNP	DLNP	DLNP	DLNP	DLNP	DLNP	DLNP	DLNP
Fasteners	66	62	2	3	28	51	2	2	2	2
Thereof screws	40	33	2	2	26	28	2	2	2	2
Tools	2	2	1	1	3	2	1	1	1	1
Uses of tools	14	11	1	1	7	4	1	1	1	1
Tool changes	4	1	0	0	2	2	0	0	0	0
Steps	46	44	4	5	18	28	3	3	3	3
Time (hh: mm:ss)	00:19: 00	00:18: 00	00:01: 40	00:01: 00	00:11: 00	00:15: 00	00:01: 00	00:01: 00	00:00: 30	00:00: 30
	Handle	Handle	Handle	Handle	Handle	Handle	Handle	Handle	Handle	Handle
Fasteners	2	27	2	2	15	14	14	14	18	21
Thereof screws	2	5	2	2	13	13	13	13	14	7
Tools	1	2	1	1	1	1	3	3	2	3
Uses of tools	1	3	1	1	2	2	4	4	3	6
Tool changes	0	1	0	0	0	0	2	2	1	2
Steps	3	5	3	3	6	5	8	8	7	10
Time (hh: mm:ss)	00:00: 30	00:04: 00	00:01: 00	00:01: 20	00:04: 00	00:04: 00	00:08: 30	00:08: 00	00:05: 00	00:07: 00
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
Fasteners	0	0	0	n/p	0	0	0	0	0	0
Thereof screws	0	0	0	n/p	0	0	0	0	0	0
Tools	0	0	0	n/p	0	0	0	0	0	0

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Uses of tools	0	0	0	n/p	0	0	0	0	0	0
Tool changes	0	0	0	n/p	0	0	0	0	0	0
Steps	3	3	3	n/p	3	3	4	4	3	3
Time (hh: mm:ss)	00:00: 10	00:00: 10	00:00: 10	n/p	00:00: 10	00:00: 10	00:00: 30	00:00: 30	00:00: 10	00:00: 10
	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board	Con-trol board
Fasteners	24	28	24	21	20	24	12	12	35	35
Thereof screws	7	9	5	5	6	7	3	3	13	13
Tools	2	2	4	3	1	2	3	3	2	2
Uses of tools	4	4	4	3	2	4	5	5	5	5
Tool changes	1	1	3	2	0	1	4	4	1	1
Steps	12	12	12	12	10	11	14	14	16	16
Time (hh: mm:ss)	00:07: 00	00:07: 00	00:06: 00	00:05: 00	00:06: 00	00:06: 00	00:07: 00	00:07: 00	00:09: 00	00:09: 00
	Main board	Main board	Main board	Main board	Main board	Main board	Main board	Main board	Main board	Main board
Fasteners	24	28	45	44	34	24	21	21	26	26
Thereof screws	7	9	13	12	20	7	11	11	9	9
Tools	2	2	5	4	2	2	2	2	1	1
Uses of tools	4	4	9	8	7	4	5	5	3	3
Tool changes	1	1	7	6	1	1	3	3	0	0
Steps	12	12	20	19	17	11	11	11	12	12
Time (hh: mm:ss)	00:07: 00	00:07: 00	00:09: 00	00:07: 30	00:10: 00	00:06: 00	00:07: 00	00:10: 00	00:07: 00	00:06: 00

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors	Capaci-tors
Fasteners	22	32	28	25	31	27	23	23	88	94
Thereof screws	13	18	13	11	18	14	12	12	58	65
Tools	1	2	4	4	3	2	3	3	5	4
Uses of tools	5	6	8	7	9	6	6	6	21	18
Tool changes	0	1	7	5	5	2	4	4	9	6
Steps	16	22	19	19	20	18	16	16	53	50
Time (hh:mm:ss)	00:08:00	00:10:00	00:09:00	00:09:00	00:13:00	00:10:00	00:13:00	00:13:00	00:36:00	00:37:00
	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt
Fasteners	76	71	70	68	82	58	42	42	80	87
Thereof screws	52	52	50	49	68	41	34	34	57	63
Tools	3	2	5	4	2	5	5	5	5	4
Uses of tools	14	14	19	17	16	13	12	12	17	16
Tool changes	4	6	17	14	2	9	7	7	7	6
Steps	41	37	43	42	45	36	36	36	47	46
Time (hh:mm:ss)	00:25:00	00:19:00	00:20:00	00:19:00	00:25:00	00:18:00	00:25:00	00:27:00	00:34:00	00:35:00
	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt	Tensio-ner pulley belt
Fasteners	83	79	n/p	n/p	22	20	16	16	80	87
Thereof screws	56	54	n/p	n/p	16	12	12	12	57	63
Tools	5	3	n/p	n/p	3	2	2	2	6	4

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Uses of tools	18	18	n/p	n/p	4	4	5	5	17	16
Tool changes	9	4	n/p	n/p	0	1	3	3	7	6
Steps	52	48	n/p	n/p	14	12	12	11	46	46
Time (hh: mm:ss)	00:29: 00	00:23: 00	n/p	n/p	00:08: 00	00:08: 00	00:09: 00	00:09: 00	00:34: 00	00:36: 00
	DBBW	DBBW	DBBW	DBBW	DBBW	DBBW	DBBW	DBBW	DBBW	DBBW
Fasteners	n/p	n/p	n/p	n/p	21	n/p	n/p	n/p	n/p	n/p
Thereof screws	n/p	n/p	n/p	n/p	21	n/p	n/p	n/p	n/p	n/p
Tools	n/p	n/p	n/p	n/p	1	n/p	n/p	n/p	n/p	n/p
Uses of tools	n/p	n/p	n/p	n/p	2	n/p	n/p	n/p	n/p	n/p
Tool changes	n/p	n/p	n/p	n/p	0	n/p	n/p	n/p	n/p	n/p
Steps	n/p	n/p	n/p	n/p	5	n/p	n/p	n/p	n/p	n/p
Time (hh: mm:ss)	n/p	n/p	n/p	n/p	00:04: 00	n/p	n/p	n/p	n/p	n/p
	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley	Tensio-ner pulley
Fasteners	84	80	77	76	52	64	n/p	n/p	89	94
Thereof screws	56	54	52	51	41	43	n/p	n/p	62	68
Tools	5	4	7	7	6	6	n/p	n/p	6	4
Uses of tools	19	19	24	23	13	18	n/p	n/p	20	18
Tool changes	10	5	22	18	7	12	n/p	n/p	9	7
Steps	54	50	53	56	34	44	n/p	n/p	57	56
Time (hh: mm:ss)	00:30: 00	00:24: 00	00:24: 00	00:23: 00	00:21: 00	00:22: 00	n/p	n/p	00:38: 00	00:40: 00
	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Fasteners	84	80	77	76	52	64	63	63	89	94
Thereof screws	56	54	52	51	41	43	48	48	62	68
Tools	5	4	7	7	6	6	6	6	6	4
Uses of tools	19	19	24	23	13	18	14	14	20	18
Tool changes	10	5	22	18	7	12	9	9	9	7
Steps	54	50	53	56	34	44	45	45	57	56
Time (hh: mm:ss)	00:30: 00	00:24: 00	00:24: 00	00:23: 00	00:21: 00	00:22: 00	00:28: 00	00:28: 00	00:38: 00	00:40: 00
	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Fasteners	6	7	5	5	27	16	53	53	7	7
Thereof screws	1	1	0	0	18	4	41	41	2	2
Tools	2	2	2	2	2	3	5	5	2	2
Uses of tools	2	2	2	2	6	4	13	13	2	2
Tool changes	1	1	1	1	1	3	7	7	1	1
Steps	8	7	6	7	22	12	40	40	8	8
Time (hh: mm:ss)	00:02: 30	00:02: 00	00:03: 00	00:02: 30	00:14: 00	00:05: 00	00:27: 00	00:27: 00	00:04: 00	00:04: 00
	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
Fasteners	117	6	4	3	4	7	6	6	82	91
Thereof screws	77	4	2	2	2	2	3	3	57	65
Tools	3	2	1	1	2	2	2	2	6	5
Uses of tools	26	2	1	1	2	2	5	5	19	20
Tool changes	13	1	0	0	1	1	3	3	9	9

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Steps	70	5	8	8	5	6	9	9	52	55
Time (hh: mm:ss)	00:37: 00	00:03: 00	00:03: 00	00:02: 30	00:03: 00	00:02: 00	00:04: 00	00:04: 00	00:45: 00	00:47: 00
	DLS	DLS	DLS	DLS	DLS	DLS	DLS	DLS	DLS	DLS
Fasteners	67	62	41	45	28	51	10	10	38	32
Thereof screws	40	33	19	20	16	28	2	2	19	13
Tools	2	2	4	3	3	2	3	3	2	2
Uses of tools	14	11	12	9	7	7	5	5	7	5
Tool changes	4	1	8	5	2	1	4	4	1	2
Steps	45	44	31	25	18	28	15	15	25	19
Time (hh: mm:ss)	00:19: 00	00:18: 00	00:12: 00	00:10: 00	00:11: 00	00:15: 00	00:06: 00	00:06: 00	00:15: 00	00:16: 00
	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS
Fasteners	20	21	33	21	22	22	16	16	49	49
Thereof screws	12	12	15	12	16	12	12	12	28	29
Tools	1	1	3	3	1	2	2	2	3	2
Uses of tools	4	4	7	6	4	4	5	5	10	7
Tool changes	0	0	7	4	0	1	3	3	3	2
Steps	15	15	16	16	14	13	12	12	31	24
Time (hh: mm:ss)	00:07: 00	00:07: 00	00:08: 00	00:07: 00	00:07: 00	00:06: 00	00:08: 00	00:07: 30	00:24: 00	00:22: 00
	CS HE	CS HE	CS HE	CS HE	CS HE	CS HE	CS HE	CS HE	CS HE	CS HE
Fasteners	n/p	n/p	n/p	n/p	24	n/p	n/p	n/p	n/p	n/p
Thereof screws	n/p	n/p	n/p	n/p	16	n/p	n/p	n/p	n/p	n/p

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Tools	n/p	n/p	n/p	n/p	2	n/p	n/p	n/p	n/p	n/p
Uses of tools	n/p	n/p	n/p	n/p	5	n/p	n/p	n/p	n/p	n/p
Tool changes	n/p	n/p	n/p	n/p	1	n/p	n/p	n/p	n/p	n/p
Steps	n/p	n/p	n/p	n/p	15	n/p	n/p	n/p	n/p	n/p
Time (hh: mm:ss)	n/p	n/p	n/p	n/p	00:07: 00	n/p	n/p	n/p	n/p	n/p
	SFF	SFF	SFF	SFF	SFF	SFF	SFF	SFF	SFF	SFF
Fasteners	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	36	31
Thereof screws	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	19	13
Tools	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n. v.	2	2
Uses of tools	n. v.	n. v.	n. v.	n. v.	n. v.	n. v.	n. v.	n. v.	7	5
Tool changes	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	1	2
Steps	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	24	18
Time (hh: mm:ss)	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p	00:15: 00	00:17: 30
	PAS	PAS	PAS	PAS	PAS	PAS	PAS	PAS	PAS	PAS
Fasteners	5	5	n/p	n/p	n/p	n/p	n/p	n/p	36	32
Thereof screws	1	1	n/p	n/p	n/p	n/p	n/p	n/p	19	13
Tools	2	2	n/p	n/p	n/p	n/p	n/p	n/p	2	3
Uses of tools	2	2	n/p	n/p	n/p	n/p	n/p	n/p	7	6
Tool changes	1	1	n/p	n/p	n/p	n/p	n/p	n/p	1	3
Steps	6	6	n/p	n/p	n/p	n/p	n/p	n/p	24	19
Time (hh: mm:ss)	00:02: 00	00:02: 00	n/p	n/p	n/p	n/p	n/p	n/p	00:14: 00	00:16: 00

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
	RDS	RDS	RDS	RDS	RDS	RDS	RDS	RDS	RDS	RDS
Fasteners	82	72	70	68	82	58	50	50	54	57
Thereof screws	58	56	50	49	68	41	42	42	44	48
Tools	3	2	5	4	2	5	5	5	3	3
Uses of tools	15	14	18	17	14	15	14	14	11	12
Tool changes	6	4	17	14	2	9	8	8	4	4
Steps	41	35	41	41	43	33	36	36	27	28
Time (hh: mm:ss)	00:27: 00	00:19: 00	00:19: 00	00:19: 00	00:32: 00	00:30: 00	00:24: 00	00:24: 00	00:20: 00	00:19: 00
	FDS	FDS	FDS	FDS	FDS	FDS	FDS	FDS	FDS	FDS
Fasteners	76	71	70	71	82	58	42	42	80	87
Thereof screws	52	52	50	49	68	41	34	34	57	63
Tools	3	2	5	5	3	5	5	5	5	5
Uses of tools	15	15	19	19	17	15	12	12	18	18
Tool changes	7	5	19	15	3	9	7	7	8	9
Steps	42	39	46	48	46	35	36	36	47	47
Time (hh: mm:ss)	00:27: 00	00:21: 00	00:23: 00	00:22: 00	00:27: 00	00:30: 00	00:29: 00	00:26: 00	00:40: 00	00:41: 00
	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower
Fasteners	19	18	46	36	25	12	9	9	19	19
Thereof screws	18	17	33	30	24	11	9	9	16	16
Tools	2	2	5	5	2	2	2	2	2	2
Uses of tools	2	2	10	9	4	2	2	2	2	
Tool changes	1	1	9	7	1	1	1	1	1	1
Steps	4	4	20	18	9	4	4	4	5	5

	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Time (hh:mm:ss)	00:03:00	00:03:30	00:10:00	00:09:00	00:06:00	00:03:00	00:04:00	00:04:00	00:04:00	00:06:00
	Fan	Fan	Fan	Fan	Fan	Fan	Fan	Fan	Fan	Fan
Fasteners	9	6	7	13	n/p	9	15	15	39	33
Thereof screws	3	1	3	3	n/p	1	12	12	20	14
Tools	2	2	2	2	n/p	2	2	2	2	3
Uses of tools	3	2	4	4	n/p	2	5	5	9	7
Tool changes	1	1	3	3	n/p	1	3	3	2	3
Steps	9	7	7	7	n/p	8	11	11	26	20
Time (hh:mm:ss)	00:02:30	00:02:00	00:03:30	00:04:00	n/p	00:02:30	00:10:00	00:10:00	00:16:00	00:17:00

Source: Own depiction

For some heat pump dryers, there are design-related, particularly relevant peculiarities which can partly explain the differences in the disassembly times of the priority parts. These are summarized in Table 40 below.

Table 40: Special features of some heat pump dryers

Dryer model and features
Manufacturer 1, HPD2
There were several cable ties used as non-reusable fasteners that did not noteworthy affect disassembly.
Manufacturer 3, HPD4
The front and rear drum seal could not be removed without destroying them.
Manufacturer 4, HPD5
There were several cable ties used as non-reusable fasteners that did not noteworthy affect disassembly.
The pump could not be removed until the motor was removed.
The drum bearing could not be removed until the rear panel of the dryer was removed.
Manufacturer 4, HPD6
There were several cable ties used as non-reusable fasteners that did not noteworthy affect disassembly.
The pump could not be removed until the motor was removed.
The drum bearing could not be removed until the rear panel of the dryer was removed.

Dryer model and features
Cable connectors on the main board were difficult to disconnect, resulting in a longer disassembly time.
Manufacturer 5, HPD7
The humidity sensor could not be removed until the drum was removed.
The condensers could only be removed after the drum had been removed.
The side panels could only be removed after the front panel was removed.
The drum bearing could not be removed until the rear panel of the dryer was removed.
Manufacturer 5, HPD8
The humidity sensor could not be removed until the drying drum was removed.
The side panels could only be removed after the front panel was removed.
The drum bearing could not be removed until the rear panel of the dryer was removed.

Source: Own depiction

As in the case of exhaust air dryers and condense dryers, not all priority parts occur in all heat pump dryers due to their design. In addition, some doors are changed as assemblies. The door parts are therefore again not used for a simplified comparison. With regard to the heat pump dryers, the indicators of the following priority parts can be added for the simplified comparison:

- pump,
- drum bearing,
- door,
- door locking nose port,
- control board,
- main board,
- capacitors,
- drum belt,
- motor,
- level sensor,
- humidity sensors,
- door lock sensor,
- coolant sensor,
- rear drum seal,
- front drum seal and
- blower.

For these priority parts, the totals of the indicators are shown in Table 41.

Table 41: Selected priority parts, dryers

Totals	MF6, HPD9	MF6, HPD 10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Fasteners	720	592	545	518	575	509	454	454	713	743
Thereof screws	460	373	329	319	439	300	337	337	473	509
Tools	36	33	58	52	36	47	56	56	49	44
Uses of tools	146	117	143	130	120	108	127	127	150	142
Tool changes	58	31	123	95	28	57	75	75	58	54
Steps	432	348	338	335	337	302	356	356	421	408
Time (hh:mm:ss)	03:51:00	02:47:00	02:36:40	02:25:20	03:28:00	02:57:30	03:56:30	03:57:00	05:01:30	05:08:30
RRP (€)	1049.00	648.00	889.00	999.00	799.00	549.00	955.00	869.00	681.00	1022.55

Source: Own depiction

The totals of the disassembly times for the heat pump dryers show greater deviations. They vary between approx. 2 hours and 25 minutes (manufacturer 1, HPD2) and slightly over 5 hours (HPD7 and HPD8 from manufacturer 5). Overall, the two models of manufacturer 1 perform best, followed by the model HPD10 of manufacturer 6. The other models of manufacturer 6 as well as the models of manufacturers 2, 3 and 4 are in the midfield. The two models of manufacturer 5 show conspicuously high totals of the disassembly times.

The large deviations in the total disassembly times are due to the installation situations of priority parts. If these parts are not accessible via the side panel behind which they are installed, and if no flaps are provided for access, this leads to higher disassembly times. The high disassembly times in the models of manufacturer 5, for example, are partly explained by the fact that the drum bearing is not accessible from the rear panel. The rear panel of the dryer, in turn, cannot be removed without first loosening the side panels. In addition, the humidity sensors could not be removed through the dryer drum on these models. Instead, the front panel had to be removed.

Furthermore, it proved advantageous if parts could be reached via maintenance flaps. This has been implemented by several manufacturers for filters, fans or pumps and is considered as good practice. In contrast, models without maintenance flaps have higher disassembly times for these parts.

A linear correlation is observed between the sum of the disassembly times and the sum of the work steps for the heat pump dryers. The correlation coefficient is r = 0.759. If the sum of the fasteners and the sum of the disassembly times are considered, the correlation coefficient is r = 0.573. This linear correlation is therefore weaker than the one between disassembly times and work steps. In the case of the heat pump dryers in this study, therefore, only the work steps appear to be suitable as an indicator for approximately representing the disassembly time. As with the other printers and dryers, it should be noted that the number of devices investigated is small.

There is no correlation between the RRP of the heat pump dryers and the total disassembly time (r = 0.182).

4.5.3.3 Conclusions for indicators

The results of the practical investigations on dryers essentially confirm the results on printers.

Here, too, the question for which indicators there is a (preferably linear) correlation to the disassembly time is relevant. In the case of the exhaust air and condense dryers, this question cannot be answered due to the small number of devices. For the heat pump dryers, as described above, there is a linear relationship to the disassembly time for both the fasteners and the work steps. However, the correlation between the number of steps and the disassembly time was stronger. This was also the case with the laser printers (see chapter 4.4.3.3).

After an overall consideration of the printers and dryers that were examined in these case studies, the number of work steps is therefore favoured as an indicator in a repairability matrix as a proxy for the disassembly time. This is implemented in the optimised scoring system (see chapter 5.1.1).

According to the results for dryers, the visibility of fasteners is not a relevant indicator. All fasteners were clearly visible and identifiable. This was also the case for the printers. This potential indicator should therefore not be included in the optimised scoring system according to the findings for both appliance groups.

For the dryers, it was also confirmed that many operations can be carried out with many different tools. Therefore, according to the findings on printers and dryers, the scoring system should assess whether tools are necessary for the repair that are not available to individual target groups.

A special working environment was not required for the work carried out on dryers. All work could also have been carried out on the customer's premises. Also, according to the results for dryers, the working environment does not seem to be a good indicator for an optimised scoring system, as it does not reflect differences between manufacturers. However, the general requirement should be that dryers can also be repaired in private households.

As far as the necessary knowledge is concerned, it must be said that the work carried out could also have been done by laypersons. In this case, longer disassembly times could be expected. This corresponds to the situation with printers. According to the findings for both groups of devices, the inclusion of the indicator knowledge in an evaluation system does not appear to be expedient.

In contrast, the indicators steps (or disassembly depth), fastener type (type of fasteners used) and type of tool should be included in an optimised scoring system. In this context, the type of tool means the target group for which it is available.

From the case studies on dryers, an additional indicator for the optimised repairability matrix is derived: The detachability of side panels. With regard to the dryers, however, it can be stated that in a simplified comparison of disassembly times across all priority parts present in all models, the dryers that perform well are those where all sides are independently detachable. Therefore, it is considered favourable for dryer repairs if each side panel, as well as front panel and rear panel, can be removed without first having to detach another side panel (or front panel, rear panel). According to the results of the case studies, it seems reasonable to include such an indicator in a repairability matrix for dryers. The indicator should therefore assess how many side panels of the dryer can be detached independently from all other side panels. The indicator should be applied to dryers and similar large household appliances.

4.5.4 Research

In addition to the practical investigations, information on several possible indicators was researched and evaluated, e. g., in user manuals, on websites and through inquiries with manufacturers.

The general approach is described in chapter 4.3. Particularities of the research procedures and the procurement of information are described in the introductory sections of the following subchapters. Furthermore, the research results on possible indicators are presented. In addition, a brief assessment is given for the possible indicators as to whether the results for dryers support inclusion in an optimised scoring system for repairability or not. An overall assessment according to the results of printers and dryers is given in chapter 5.

4.5.4.1 Spare parts

As with the printers, the process of obtaining various spare parts for repairs was also replicated for the dryers. The information required for this was obtained and documented. This includes, in particular, availability, delivery times and costs. Particular challenges and differences between manufacturers and models were noted and are presented below in this subchapter.

4.5.4.1.1 Selection of spare parts

In order to limit the large number of possible spare parts, a few parts were specifically selected for further research. For two selected devices, information on all spare parts was researched in order to test the optimised scoring system on them. The information on the spare parts for the two selected devices is presented in Appendix A. The results of the application of the optimised scoring system presented in chapter 6. In order to evaluate all tumble dryers using the scoring system, information on all spare parts for all devices would be necessary.

At this point, a selection of spare parts with different characteristics was made. Care was taken to select parts with different properties whose replacement requires more or less effort and technical knowledge. Table 42 provides an overview of the selected parts.

Table 42: Selection of spare parts

Selected part	Characteristics
Pump (for heat pump dryers)	Usually accessible without opening the housing (using a flap in the back panel) Replacement usually requires relatively more technical knowledge. According to the brief survey of repairers, this spare part is repaired relatively often.
Drum bearing	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Door	Usually accessible without opening the housing and can be changed with relatively little technical knowledge.
Motor capacitors	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Drum belt	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.

Selected part	Characteristics
Motor	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Humidity sensor	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.
Blower	Replacement usually requires more effort, including opening the housing and relatively more technical knowledge.

Source: Own depiction

4.5.4.1.2 Information gathering

To check the availability, delivery times, prices and costs of the selected dryer spare parts, the following research steps were carried out:

- Research on website (manufacturers and authorised service partners).
- Written inquiries (e-mail and chat) with manufacturers and authorised service partners.
- Telephone inquiries with manufacturers and authorised service partners.

4.5.4.1.3 Identification of spare parts

As described for printers, the first prerequisite for procuring spare parts is that they are clearly identified and can be ordered by means of a unique (item) number. Identification was just as challenging with the dryers as with the printers. Here, too, the identifiability of spare parts essentially depends on whether an exploded view including unique (item) numbers is provided. This exploded view is part of the information provided for some devices. This aspect is therefore described in more detail in chapter 4.5.4.2.4.

4.5.4.1.4 Availability of spare parts

It was examined whether the selected spare parts (see Table 43) are available for repairs. This is initially independent of the costs of the spare parts or the delivery times. In each case, a request was made and a distinction made as to whether the parts were made available to the three target groups of lay persons, professional repairer and authorised service partners (see Chapter 4.3).

The results for exhaust air dryers show that for the two models EAD1 (manufacturer 1) and EAD2 (manufacturer 4) all of the spare parts considered are made available to all three target groups.

The results on the availability of the selected spare parts for condense dryers are summarised in Table 43.

Table 43: Availability of spare parts, condense dryers

Target group	MF6, CDD2	MF6, CDD3	MF1, CDD1
	Drum bearing	Drum bearing	Drum bearing
Lay person	No	No	Yes
Professional repairer	No	No	Yes

Target group	MF6, CDD2	MF6, CDD3	MF1, CDD1
Authorised service partner	Yes	Yes	Yes
	Door	Door	Door
Lay person	Yes	Yes	Yes
Professional repairer	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes
	Motor capacitors	Motor capacitors	Motor capacitors
Lay person	No	No	Yes
Professional repairer	No	No	Yes
Authorised service partner	Yes	Yes	Yes
	Drum belt	Drum belt	Drum belt
Lay person	No	No	Yes
Professional repairer	No	No	Yes
Authorised service partner	Yes	Yes	Yes
	Motor	Motor	Motor
Lay person	No	No	Yes
Professional repairer	No	No	Yes
Authorised service partner	Yes	Yes	Yes
	Humidity sensor	Humidity sensor	Humidity sensor
Lay person	Yes	Yes	Yes
Professional repairer	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes
	Blower	Blower	Blower

Target group	MF6, CDD2	MF6, CDD3	MF1, CDD1
Lay person	No	No	Yes
Professional repairer	No	No	Yes
Authorised service partner	Yes	Yes	Yes

Source: Own depiction

Examination of the table shows that only the door and the humidity sensor are made available by all manufacturers for all models and target groups. Manufacturer 1 also makes all other spare parts available to all target groups. Manufacturer 6 only makes the other spare parts available to authorised service partners. This shows that the availability of spare parts depends on the respective manufacturer. All the spare parts considered are at least available to authorised service partners.

The results on the availability of the selected spare parts for heat pump dryers are summarised in Table 44.

Table 44: Availability of spare parts, heat pump dryers

Target group	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Door	Door	Door	Door	Door	Door	Door	Door	Door	Door
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes

Target group	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes
Authorised service partner	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	DBT	DBT	DBT	DBT	DBT	DBT	DBT	DBT	DBT	DBT
Lay person	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
Lay person	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No
Professional repairer	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No
Authorised service partner	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower

Target group	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Lay person	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Professional repairer	No	No	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Own depiction

Table 44 shows that none of the investigated spare parts are available for all target groups across all models. The condensation water pump, the drum bearing, the drum belt and the motor are the parts that are provided for all authorised service partners. With the HPD9 from manufacturer 6, one dryer model stands out in that only four of the selected spare parts are available even for authorised service partners.

It is also noticeable that two manufacturers make all selected spare parts for their heat pump dryers available to all three target groups. Overall, it is clear that this very good spare parts supply is also implemented by precisely these manufacturers for the condensation and exhaust air dryers.

It is also noticeable with other manufacturers that the availability of a spare part is more often the same for different models for the three target groups. This also applies when condensation and heat pump dryers are considered together.

It is thus confirmed that the availability of spare parts for dryers, unlike for printers, is primarily dependent on the manufacturer's policy and only secondarily on the model.

In the course of the inquiries, service staff gave reasons for the partly restrictive spare parts policy. Several times it was stated that the manufacturer would not make safety-related spare parts available to lay persons or repairers who are not authorised service partners. Three dryer manufacturers unanimously added the argument that lay persons would endanger themselves through repairs if they had access to more spare parts. Clear definitions of such safety-related parts could not be given. Some employees said that all “internal” spare parts are not made available. The reasoning is not very understandable, as spare parts are also affected to which no 220 V is applied. In addition, lay persons can also obtain the spare parts for other actors, e. g., professional repairer employed by them. They are able to carry out all kinds of repairs. Furthermore, some manufacturers show that a customer-friendly spare parts policy can be implemented without invoking safety relevance. Since the argument of safety relevance is systematically used to justify a restrictive spare parts supply, it should be considered to integrate the manufacturer's spare parts policy into an optimised scoring system for repairability (for possible implementation see chapter 5.2.2.).

4.5.4.1.5 Duration of availability

As already explained, the case study on printers showed that the availability of spare parts is handled very flexibly in terms of time and depends strongly on the sales figures of printer models. Therefore, the manufacturers were also asked whether they guarantee the availability of spare parts for a certain period of time after the device has been placed on the market. This inquiry was also carried out for the dryers.

In contrast to printer manufacturers, where no manufacturer guarantees an availability period, such guarantees do occur with dryer manufacturers. There are great differences between the manufacturers. Manufacturer 4 promises that the spare parts provided will be available for 15 years. Manufacturer 1 promises this for ten years. For the other four manufacturers, the guaranteed availability is two years each. The two manufacturers with a longer guaranteed availability of spare parts are the manufacturers who also implement a comprehensive availability of spare parts for lay persons.

The results for dryers show once again that the duration of spare parts availability should be included in an evaluation system for repairability. If spare parts can no longer be obtained after a short period of time, this severely limits the repairability of devices. When assessing repairability, a device for which a manufacturer guarantees the availability of spare parts over a longer period of time should therefore be rated better for this promise than a device for which no or only a short availability of spare parts is guaranteed (for possible implementation in a repairability matrix, see 5.2.3.).

4.5.4.1.6 Delivery time

As explained for the printers, in addition to the availability of spare parts, their delivery time can also influence whether they are available in practice.

The delivery times for lay persons were requested from the dryer manufacturers and authorised service partners for the selected spare parts.

The results for exhaust air dryers show that the delivery times for the selected spare parts are all one to two days. This seems to be due to the fact that the two exhaust air dryers considered are produced by the two manufacturers that have the most customer-friendly spare parts strategies overall.

The results for condensation dryers are summarised in Table 45. Here, “n/a.” stands for “no availability” and is given, if the information is not given, because the spare part is not available. The abbreviation “n/s” stands for “no specified information” and is given, if the spare part is available but the information about the delivery time is not.

Table 45: Delivery times (in days) for spare parts, condense dryers

Spare part	MF6, CDD2	MF6, CDD3	MF1, CDD1
Drum bearing	n/s	n/s	1 – 2
Door	7	7	1 – 2
Motor capacitors	n/s	n/s	1 – 2
Drum belt	n/s	n/s	1 – 2
Motor	n/s	n/s	1 – 2
Humidity sensor	1 – 2	1 – 2	1 – 2
Blower	n/s	n/s	1 – 2

Source: Own depiction

The delivery times for the model of the customer-friendly manufacturer are also one to two days here. For the other manufacturer, it is one to two days or one week. This manufacturer has not provided any information on many delivery times, which may be due to the fact that these parts are not available to lay persons.

The delivery times (for lay persons) for selected spare parts for heat pump dryers are shown in Table 46.

Table 46: Delivery times (in days) for spare parts, heat pump dryers

Spare part	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Condensation water pump	n/s	n/s	1 – 2	1 – 2	n/s	n/s	1 – 2	1 – 2	1 – 2	1 – 2
Drum bearing	n/s	n/s	1 - 2	1 - 2	n/s	n/s	1 - 2	1 - 2	1 - 2	1 - 2
Door	n/a	n/a	1 - 2	14 - 21	n/a	n/s	1 - 2	1 - 2	14 - 21	14 - 21
Motor capacitors	n/a	n/s	1 - 2	1 - 2	n/s	n/s	1 - 2	1 - 2	1 - 2	1 - 2
Drum belts	n/s	n/s	14 - 21	1 – 2	2 – 3	n/s	1 – 2	1 – 2	1 – 2	1 – 2
Motor	n/s	n/s	1 – 2	1 – 2	n/s	n/s	1 – 2	1 – 2	1 – 2	1 – 2
Humidity sensor	n/a	1 - 2	1 - 2	1 - 2	2 - 3	n/s	1 – 2	1 – 2	1 - 2	1 - 2
Blower	n/a	n/s	1 - 2	1 - 2	n/s	n/s	1 - 2	1 - 2	1 - 2	1 - 2

Source: Own depiction

In terms of delivery times, the manufacturers' models which also have a good spare parts availability, are the best with a delivery time of one to two days. Other manufacturers also indicate one to two days for some spare parts, and two to three weeks for others. It is noticeable that three manufacturers did not provide any information on the delivery time for several spare parts.

Compared to printers, there are fewer outliers in the delivery times for dryer spare parts. Delivery times of eight to ten weeks do not occur for dryers. Nevertheless, there are clear differences in the delivery times of the various dryer models. This is especially true for heat pump dryers, where models from several different manufacturers are part of the case study.

It makes a difference whether dryers are out of action for at least one to two days or two to three weeks longer because a spare part has to be delivered. Therefore, according to the results for dryers this indicator should be included in an optimised scoring system.

4.5.4.1.7 Costs

Besides very long delivery times, very high costs for spare parts can also limit their actual availability. For the case study, the costs of the selected dryer spare parts (see Table 42) were requested.

The costs for exhaust air dryers are shown in Table 47 below. The absolute costs in euros and the costs as a percentage of the RRP are given. (All prices given are gross prices.) The RRP is used in Table 47 because offer prices can change.

Table 47: Costs (in €) for spare parts, exhaust air dryers

Spare part	Manufacturer 1, EAD1	Manufacturer 4, EAD2
RRP (€)	589.00	778.86
	Drum bearing	Drum bearing
Costs (€)	17.90	33.20
% of RRP	3.04	4.26
	Door	Door
Costs (€)	57.60	206.71
% of RRP	9.78	26.54
	Motor capacitors	Motor capacitors
Costs (€)	6.99	17.37
% of RRP	1.19	2.23
	Drum belt	Drum belt
Costs (€)	19.60	39.03
% of RRP	3.33	5.01
	Motor	Motor
Costs (€)	124.60	428.40
% of RRP	21.15	55.00
	Humidity sensor	Humidity sensor
Costs (€)	6.05	36.60
% of RRP	1.03	4.70
	Blower	Blower
Costs (€)	6.76	40.10

Spare part	Manufacturer 1, EAD1	Manufacturer 4, EAD2
% of RRP	1.15	5.15

Source: Own depiction

There is a wide range of variation in spare parts for the exhaust air dryers. Most of the parts considered cost up to about 5% of the RRP. The door and the motor are the parts that cost more for both manufacturers. The price of the motor is particularly high for the EAD2 from manufacturer 4, which costs about 430 € in absolute terms. This is 55% of the RRP of this dryer.

The costs for condense dryers are shown in Table 48 below.

Table 48: Costs (in €) for spare parts, condense dryers

Spare part	MF6, CDD2	MF6, CDD3	MF1, CDD1
RRP (€)	439.00	467.01	679.00
	Drum bearing	Drum bearing	Drum bearing
Costs (€)	13.70	13.70	17.90
% of RRP	3.12	2.93	2.64
	Door	Door	Door
Costs (€)	37.84	37.84	71.33
% of RRP	8.62	8.10	10.51
	Motor capacitors	Motor capacitors	Motor capacitors
Costs (€)	13.70	13.70	6.69
% of RRP	3.12	2.93	0.99
	Drum belt	Drum belt	Drum belt
Costs (€)	15.72	15.72	11.60
% of RRP	3.58	3.37	1.71
	Motor	Motor	Motor
Costs (€)	82.81	82.81	124.93
% of RRP	18.86	17.73	18.40
	Humidity sensor	Humidity sensor	Humidity sensor

Spare part	MF6, CDD2	MF6, CDD3	MF1, CDD1
Costs (€)	11.90	11.90	7.25
% of RRP	2.71	2.55	1.07
	Blower	Blower	Blower
Costs (€)	12.68	12.68	6.50
% of RRP	2.89	2.72	0.96

Source: Own depiction

The prices of the selected spare parts for condense dryers have a smaller fluctuation range than those for exhaust air dryers. The doors and motors are again the spare parts with comparatively higher prices. As a percentage of the RRP, doors are up to about 10% and motors are just under 20% of the RRP.

The costs for the selected spare parts for heat pump dryers are shown in Table 49 below.

Table 49: Costs (in €) for spare parts, heat pump dryers

Costs	MF6, HPD9	MF6, HPD 10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
RRP (€)	1049.00	648.00	889.00	999.00	799.00	549.00	955.00	869,00	681.00	1022.55
	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump	Pump
Costs (€)	43.69	45.71	30.45	56.50	125.00	159.00	112.69	112.69	58.78	58.92
% of RRP	4.16	7.05	3.43	5.66	15.64	28.96	11.80	12.97	8.63	5.76
	DB	DB	DB	DB	DB	DB	DB	DB	DB	DB
Costs (€)	16.76	16.96	14.45	17.90	190.00	159.00	14.64	14.64	49.95	40.28
% of RRP	1.60	2.62	1.63	1.79	23.78	28.96	1.53	1.68	7.33	3.94
	Door	Door	Door	Door	Door	Door	Door	Door	Door	Door
Costs (€)	n/a	n/a	49.36	93.71	n/a	159.00	197.54	197.54	121.13	451.93
% of RRP	n/a	n/a	5.55	9.38	n/a	28.96	20.68	22.73	17.79	44.20
	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC

Costs	MF6, HPD9	MF6, HPD 10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Costs (€)	n/a	29.16	7.21	6.69	20.43	159.00	31.06	31.06	33.95	15.26
% of RRP	n/a	4.50	0.81	0.67	2.56	28.96	3.25	3.57	4.99	1.49
	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt	Drum belt
Costs (€)	25.17	15.37	14.45	16.20	23.57	159.00	39.03	39.03	59.95	49.41
% of RRP	2.40	2.37	1.63	1.62	2.95	28.96	4.09	4.49	8.80	4.83
	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor	Motor
Costs (€)	92.39	79.00	140.31	140.31	109.20	159.00	337.96	337.96	176.95	127.81
% of RRP	8.81	12.19	15.78	14.05	13.67	28.96	35.39	38.89	25.98	12.50
	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS
Costs (€)	n/a	11.90	6.51	7.25	30.13	159.00	33.70	33.70	12.95	10.06
% of RRP	n/a	1.84	0.73	0.73	3.77	28.96	3.53	3.88	1.90	0.98
	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower	Blower
Costs (€)	n/a	16.96	7.06	7.06	33.57	159.00	47.01	47.01	39.95	29.62
% of RRP	n/a	2.62	0.79	0.71	4.20	28.96	4.92	5.41	5.87	2.90

Source: Own depiction

With regard to the spare parts prices quoted for the authorised service partner of manufacturer 3, it should be noted that this partner generally charges a flat rate of 159.00 €, irrespective of the defective part. The survey revealed that the authorised service partner does not have a spare parts price list and instead works with the flat rate price, which also includes the repair costs. Therefore, a price of almost 30% of the RRP is given for each spare part for the corresponding model. In most cases, this is clearly the highest price compared to the other models. However, for the motor, two other models have a price of almost 40% of the RRP. For the door, one model is above the percentage price (almost 30%) of the dryer HPD4 from manufacturer 3, and HPD8 from manufacturer 5 is 44% of the RRP for a door. Doors also reach more than 20% of the RRP for two other models.

Across all dryer types, doors and motors tend to be the most expensive spare parts in absolute terms and as a percentage of the RRP. For these spare parts, spare parts prices also occur for dryers in dimensions that can prevent repairs. According to experience with this product group, spare part costs should be included in an assessment of repairability. In the case of dryers, however, the dimensions are not reached that were partly found in the case of printers.

4.5.4.2 Repair-relevant information

In this chapter the research results on the availability of information relevant to repairs and troubleshooting are briefly presented.

4.5.4.2.1 Information gathering

As with printers, to research which repair-relevant information the manufacturers offer to which target groups, the following research steps were carried out:

- Research on the manufacturer's websites and evaluating the information.
- Written inquiries with the manufacturer and authorised service partners.
- Telephone inquiries with the manufacturer and authorised service partners.
- Research on third party websites and evaluation of the information to assess the importance of information materials.

The purpose of the search on the websites was to check which manuals and documentation as well as further information are offered there. The user manuals and documentation found were then searched for information serving repairs. In the following, the term “user manual” is used synonymously for similar terms used by the manufacturers, such as online manual, instruction manual, operating instructions, etc.). Written and telephone inquiries were made in all cases with regard to repair manuals and circuit diagrams, as these were not publicly available. Telephone enquiries were carried out when written enquiries did not yield results. In addition to obtaining information from the manufacturers, third-party websites were searched for repair-relevant information. With regard to the dryers, this search was not successful.

The following subchapters explain to what extent repair-relevant information on the dryer models investigated is provided by the manufacturers and whether there are differences between manufacturers and dryer models. If relevant, it is briefly shown whether the information proved to be necessary and helpful in the case studies and what challenges may arise if this information is not available.

4.5.4.2.2 User manuals and set-up instructions

It was investigated which information is routinely provided by the manufacturers on websites. Almost all manufacturers provide user manuals and brief instructions on their websites for all dryer models examined.

As with the printers, the evaluation of these documents showed that they contain little or no repair-relevant information. One exception is the error code tables that are included in some user manuals.

Even after the results on dryers, the availability of user manuals should therefore not be included in the optimised scoring system. They should only be checked to see if they contain the information that is considered relevant (exploded views, fault code tables, repair manuals, circuit diagrams).

4.5.4.2.3 Error code tables

As already described for the printers, the indicator error code tables must be seen in connection with the indicator diagnostic interface. An examination of the diagnostic interfaces for error diagnosis shows first of all that error information is given in coded form for all dryers. In 14 out of 15 devices, the error codes are indicated by flashing LEDs and in the dryer display. In many cases, an “F” followed by a number is shown. In the case of the HPD4 from manufacturer 3, error messages are only shown via LED flashes. Since all the dryers examined have coded interfaces, an error code table is also necessary for all of them. If this is not the case, it should lead to a point deduction in an evaluation system.

For almost all dryer models, error code tables were publicly available, in the user manual or on the websites. They are therefore available to all three target groups. Only for the HPD4 of manufacturer 3 was no error code table publicly available. In this case, after several inquiries, it was possible to clarify with an authorised service partner that the error code table is available to the company. However, it is not made available to lay persons or professional repairer. The availability is only given for one target group.

A closer look at the error code tables shows that their scope differs in part. Two heat pump dryers (HPD5, manufacturer 4 and HPD6, manufacturer 4) have error code tables that are comparatively extensive and informative. These two tables have more than 80 entries. Many error codes are thus explained comparatively precisely, e. g., with the entry: Electronic error/motor drive defective. The other error code tables are much shorter and explain errors less precisely in some cases. Several times, for example, “electronic error” is given without any further explanation.

The example of the models with the extensive error code tables shows that it is also possible to offer lay persons information about which spare parts could be affected before the repair decision is made. The results on dryers also show that the availability of error code tables should be taken into account when assessing repairability.

4.5.4.2.4 Exploded view drawings

As already described for the printers, the first prerequisite for the procurement of spare parts is that they can be easily and clearly identified. As with the printers, it was sometimes necessary to make several telephone or written inquiries with the manufacturers to clarify which spare part should be ordered for which model. The designation of some spare parts in dryers is relatively clear and they only occur once in the device (e. g., pump, drum belt, etc.). However, even with such spare parts, it was not always possible to clearly identify, for example in Internet shops, whether a part offered fits the dryer model investigated. In the case of sensors, of which there are several in a dryer, it was in some cases particularly challenging to identify the sensor we were looking for (in this case the humidity sensor) for the model we were investigating.

As with the printers, the identification of spare parts was only satisfactorily possible if exploded views were made available by the manufacturers or authorised service partners. In this context, an exploded view is a graphical representation showing the appearance of spare parts and the location where they are installed in the device. In addition, the exploded view must also include unique item or part numbers.

Table 50 shows for which exhaust air and condense dryers exploded views are provided by the manufacturers for each target group.

Table 50: Availability of exploded view, exhaust air and condense dryers

Target group	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Lay person	Yes	No	Yes	Yes	Yes

Target group	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Professional repairer	Yes	Yes	Yes	Yes	Yes
Authorised service partner	Yes	Yes	Yes	Yes	Yes

Source: Own depiction

For the exhaust air and condense dryers, the manufacturers make the exploded views available quite comprehensively. Only manufacturer 4 makes the statement that exploded views are made available on presentation of an electrotechnical training certificate. Lay persons without this training certificate, on the other hand, cannot obtain the exploded view.

Table 51 shows for which heat pump dryers exploded views are provided by the manufacturers for each target group.

Table 51: Availability of exploded view, heat pump dryers

Target group	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5, HPD8
Lay person	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Professional repairer	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Own depiction

The overall view of Table 50 and Table 51 shows that the availability of the exploded view depends on the manufacturer, but not on dryer models. Manufacturer 1 and manufacturer 6 also make exploded views available to lay persons and thus to all target groups considered for all dryer models examined. In one case, the comprehensive exploded views are publicly available on the internet. In the second case, they are made available by the customer service very quickly and easily on request. The exploded views of these manufacturers enable the clear identification of spare parts and contain clear article numbers. Manufacturer 4 provides exploded views upon presentation of an electrotechnical training certificate. Manufacturers 3, 4 and 6 only make the exploded views available to authorised service partners.

The results for dryers also show that the availability of an exploded view should be included in an optimised scoring system. The exploded view must be accompanied by a clear listing of part/item numbers or codes.

4.5.4.2.5 Repair manuals

Repair manuals show the steps that must be carried out to rectify faults and also indicate their intended sequence.

Repair manuals were not found publicly on the manufacturer's websites or in the manuals of any manufacturer or authorised service partner.

All manufacturers were asked about the availability of repair manuals. The answers for the exhaust air and condensation dryers are shown in Table 52 below.

Table 52: Availability of repair manuals, exhaust air and condense dryers

Target group	MF1, EAD1	MF4, EAD2	MF6, CDD2	MF6, CDD3	MF1, CDD1
Lay person	No	No	No	No	No
Professional repairer	No	Yes	No	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes

Source: Own depiction

The answers for the exhaust air and condensation dryers show that the availability of repair manuals does not depend on individual dryer models, but on the respective manufacturer. Manufacturer 4 states that repair manuals are made available upon presentation of an electrotechnical training certificate. Lay persons cannot obtain the instructions. The other manufacturers do not make repair manuals available to lay persons or professional repairers.

Table 53 shows for which heat pump dryers repair manuals are or are not made available by the manufacturers.

Table 53: Availability of repair manuals, heat pump dryers

Target group	MF6, HPD9	MF6, HPD10	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF 5, HPD7	MF 5, HPD8
Lay person	No	No	No	No	No	No	No	No	No	No
Professional repairer	No	No	No	No	No	No	Yes	Yes	No	No
Authorised service partner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Own depiction

In the case of heat pump dryers, too, only manufacturer 4 states that professional repairers are provided with the repair manuals on presentation of an electrical engineering training certificate. All other manufacturers only make the repair manuals available to their authorised service partners.

According to the manufacturer, the instructions are usually made available electronically. Authorised service partners of manufacturers typically access a database containing repair manuals for several models. Repair manuals, circuit diagrams and extensive error code tables are typically stored together in the database. Authorised service partners usually pay an annual fee to access the database.

According to the repair company with which the practical investigations were carried out, repair manuals are also helpful for dryers. Their availability should therefore be included in an evaluation system.

4.5.4.2.6 Circuit diagrams

Circuit diagrams were mentioned as very helpful relevant information by the repair company with which the practical investigations were carried out. A circuit diagram shows the course of currents and voltages in a device. For all installed parts it shows what voltage must be present there during fault-free operation and what current the part must absorb. Circuit diagrams are used to identify faults and errors (see also chapter 4.4.4.2.6).

Circuit diagrams are not publicly available from any manufacturer for any model. When asked, the manufacturers provide the same information as for the repair manuals. Manufacturer 4 states for all models that circuit diagrams are provided upon presentation of an electrotechnical training certificate, i. e., for professional repairer. All other manufacturers state for all models that circuit diagrams are only made available to authorised service partners.

As described above, circuit diagrams are typically made available together with repair manuals and detailed fault code tables in a database to authorised service partners who pay an annual fee.

Circuit diagrams are very relevant for locating and identifying faults during repair. They are also used to check whether faults have been rectified with the repair. Their availability should be included in an assessment of repairability.

The possibilities of considering the repair-relevant information mentioned in this subchapter in an evaluation system are discussed in see chapter 5.2.6.

4.5.4.3 Diagnostic interfaces

In this chapter the research and results on interfaces are briefly described. The type of interfaces was gathered from the user manuals and from the manufacturers' websites and checked on the devices. The following subchapters summarise the results for each manufacturer.

4.5.4.3.1 Types of diagnostic interfaces

As described, diagnostic interfaces serve to identify errors that have occurred. They are therefore relevant for repairs, especially initial repair decisions.

The types of diagnostic interfaces in the dryer models under consideration have already been briefly described in chapter 4.5.4.2.3. All dryers have coded interfaces. In the case of the devices EAD1, manufacturer 1 and EAD2, manufacturer 4, flashing signs of an LED are used for this purpose. With the other devices, coded error messages are shown on a display. In many cases, this takes the form of the letter “F” followed by a number.

As already explained for the printers and in 4.5.4.2.3, it is important to consider diagnostic interfaces and error code tables, with the help of which the coded errors can be translated, together. (A possible implementation in a rating system is shown in 5.2.7).

In addition to the coded interfaces, two manufacturers also use data interfaces in the heat pump dryers that were examined by these manufacturers. Manufacturer 4 uses optical interfaces and manufacturer 5 uses USB connections. In both cases, the software used to read out the interface is not publicly available. The interfaces are therefore proprietary interfaces. According to the manufacturers' statements, the software is available to their authorised service partners for a fee.

According to the results on dryers, an evaluation of interfaces should at least map coded interface and proprietary hardware interfaces.

4.5.4.4 Software and firmware

For the dryers, only the firmware indicator is relevant. Results on its availability are recorded below. The software for operating networked devices is not discussed further, as the devices should also function without the networking function.

4.5.4.4.1 Information gathering

In order to research which firmware the manufacturers offer to which target groups, three research steps were carried out:

- research on website of manufacturers and authorised service partners,
- written inquiries with manufacturers and authorised service partners and
- telephone inquiries with manufacturers and authorised service partners.

Information on the availability of firmware was only provided by manufacturers and authorised service partners in the written and telephone inquiries.

4.5.4.4.2 Availability of firmware

None of the dryer manufacturers make the firmware available to lay persons or competent repairers. Regarding authorised service partners, almost all manufacturers guarantee that updated firmware will be made available for the same duration as the physical spare parts. Manufacturer 3 does not provide any information on this. The duration is therefore 15 years for manufacturer 4 and ten years for manufacturer 1. Manufacturers 2, 5 and 6 guarantee availability for two years. Due to the large differences in availability duration, the results for the dryers also show that this possible indicator should be included in an optimised scoring system (for possible implementation see chapter 5.2.8).

5 Development of an optimised scoring system for repairability

In this chapter, the indicators, the selected evaluation classes and the scoring of an optimised scoring system for repairability are presented. An important basis for the optimised repairability matrix is the example of a scoring system contained in the EN 45554 standard. However, the optimised scoring system also includes indicators derived from the case studies (see chapter 4) or from other existing approaches for assessing repairability (see chapter 3). How the indicators and valuation classes selected here relate to those from the example of a scoring system from the EN 45554 standard is briefly explained in each case.

For the optimised scoring system, a point scale from zero to ten points is used. The scoring starts at zero points if repairs are prevented by an issue. It starts at one point if repairs are made more difficult but not prevented. It should be noted that the point scale must be adjusted accordingly if there are minimum requirements for repairability that guarantee, for example, the availability of spare parts. Furthermore, guidance on the application of the individual indicators in the assessment of repairability is presented, as well as guidance on necessary information to be provided by manufacturers to a monitoring body.

In principle, it is assumed that there should be a monitoring body if the optimised scoring system is to be widely applied. In this case, manufacturers must provide certain information to this body in order to enable the application of indicators. The information required is given below for each indicator. This procedure makes it possible to assess the repairability of devices without having to carry out serial tests on all devices. Instead, a monitoring body could (randomly) check the manufacturer's information. In principle, it is still assumed that the repairability of devices is assessed once, usually when they are placed on the market for the first time. How individual indicators can be used to make this possible is described in the following subchapters.

For each indicator, it is suggested below whether the assessment should be done at device level or at part level. Where it seems practicable, it is suggested to score at the device level to minimise the administrative burden of applying the optimised scoring system.

How the points received by individual devices when assessing repairability at device or part level for each indicator can be added up to an overall score is presented in chapter 6.

5.1 Indicators that follow from the practical investigations

5.1.1 Disassembly depth

The disassembly depth of each part is the number of steps to be performed to disassemble the part. The number of steps has proven to be an indicator that can be used to approximate the disassembly time of spare parts. The indicator disassembly depth is assessed at the part level, i. e., for each priority part.

The number of steps is already a numerical number, so one can compare work steps of devices among each other. However, this does not help, if only the repairability of one device is to be assessed at a time. The number of steps is particularly meaningful in comparison with other devices. Furthermore, although a ranking of devices can be formed from the number of work steps, it is unclear how the difference between devices should be included in the evaluation. For example, the number of steps required to dismantle a motor may be very similar for two devices, while another device may require approximately twice the number of steps. A ranking (1st, 2nd, 3rd) would then penalise the 2nd ranked device and not reflect the poor performance of the 3rd ranked device.

One approach to solving these two challenges is to use reference values. It is then possible to evaluate how far a number of steps deviates from this reference value. The approach of working with reference values is also part of the evaluation system proposed in the EN 45554 standard.

In the context of this project, the number of work steps for the disassembly of all priority parts was determined for all devices that are part of the case study. The mean value for each priority part over all devices of a device group (e. g., all laser printers, heat pump dryers) can serve as a reference value. The mean values of the steps for laser printers and heat pump dryers were used for the exemplary evaluation of devices (see chapter 6) and are presented in Appendix B.

For the optimised scoring system, the approach of dividing different deviations from the mean value into valuation classes is chosen. The use of valuation classes corresponds to the procedure for the other indicators and makes the indicators comparable with each other. A utility value analysis was chosen for the implementation of the evaluation (see chapter 6.2).

The intervals for the valuation classes were chosen to reflect ranges for the devices that were part of the case studies. The selected assessment classes A to E for the indicator disassembly depth are shown in Table 54 below. Points 0 to 10 are awarded for the assessment classes A to E.

Table 54: Indicator disassembly depth

Indicator	Assessment level	Valuation classes	Point scale
Disassembly depth	Part	A: The number of work steps required is ≤ 70% of the mean value B: The number of work steps required is > 70 to ≤ 90% of the mean value C: The number of work steps required is > 90 to ≤ 110% of the mean value D: The number of work steps required is > 110 to ≤ 130% of the mean value E: The number of work steps required is more than > 130% of the mean value	A = 10 B = 7 C = 4 D = 1 E = 0

Source: Own depiction

Guidance for the application and monitoring of the indicator:

Manufacturers must submit repair manuals to a monitoring body that show the steps to disassemble each priority part. This allows a monitoring body to check the disassembly depth against documentation without having to carry out time-consuming investigations on each device. Random checks of the information are also possible. In this context, it is important that a clear definition is made as to what is counted as one work step.

Reference values are needed to apply the indicator. These can be established through practical investigations or set by a monitoring body or panel. Reference values should be adjusted regularly to reflect technical progress.

5.1.2 Fastener type

The indicator fastener type assesses how two connected parts can be detached from each other. The most favourable type of attachment in terms of repairs are reusable fasteners that do not need to be replaced during reassembly.

This type of fastener, such as screws or click connections, was widely used in the devices examined in the case studies. Nevertheless, fastener types that cannot be removed (e. g., potted parts) are conceivable. This can make the replacement of parts impossible. Therefore, other fastener types are also considered in the evaluation classes for this indicator.

The exemplary scoring system in the standard EN 45554 also includes an indicator for fasteners. The classes A to C chosen there (reusable, removable and neither reusable nor removable) cover the conceivable cases well. They are therefore adopted for an optimised scoring system, The scoring classes A to C for the fastener type indicator are shown in Table 55 below. Zero points are awarded for fasteners that are neither removable nor reusable, as this makes the replacement of parts impossible. The scale of points is shown in Table 55.

Table 55: Indicator fastener type

Indicator	Assessment level	Valuation classes	Point scale
Type of fastener	Part	A: Reusable B: Removable C: Neither reusable nor removable	A = 10 B = 5 C = 0

Source: Own depiction

The indicator type of fastener is evaluated at the part level. For each priority part, the least favourable attachment is evaluated. I. e., rating class A is assigned if all fasteners can be reused when dismantling a part. If at least one fastener can be removed but not reused, rating class B is assigned.

Guidance for the application and monitoring of the indicator:

As previously described, manufacturers must provide a monitoring body with repair manuals that map the intended steps for disassembly of each priority part. The repair manuals and work steps shall identify the types of fasteners to be disconnected.

5.1.3 Tool type

The indicator tool type assesses the types of tools needed to disconnect fasteners.

Regarding the type of tool, it is particularly relevant, for which target group they are available. Repairs can be carried out by most actors if tools are publicly available / i. e., also available to lay persons. If proprietary tools are needed, which can only be acquired by actors of individual target groups, this can hinder repairs.

The case studies showed that the operations carried out there, could be done with freely available and common tools. However, there are cases in which special tools are needed for repairs that are not available to all actors.

Therefore, the valuation classes A to D selected for the optimised scoring system reflect whether tools are needed that are available to all or only some of the target groups considered in the project (lay persons, professional repairers, authorised service partners/manufacturers). If the repair cannot be carried out with any available tool, zero points are awarded. The valuation classes and the corresponding point scale are shown in the following Table 56.

Table 56: Indicator tool type

Indicator	Assessment level	Valuation classes	Point scale
Tool type	Part	A: Repair possible without tools, with standard tools commercially available to lay persons or with tools supplied. B: Repair possible with specific tools that are not supplied but can be purchased by professional repairer. C: Repair possible with specific tools that are not supplied but can be purchased by authorised service partners. D: Repair cannot be carried out with any standard, supplied or purchaseable tools.	A = 10 B = 7 C = 3 D = 0

Source: Own depiction

The indicator tool type is assessed at the part level. For each priority part, the tool that can be obtained least easily is rated. I. e., the rating class A is assigned if only tools that can be purchased by lay persons are needed for the disassembly of a part. As soon as a tool is needed that can only be obtained by an authorised service partner, rating class C is assigned.

In the example of a scoring system in the EN 45554 standard, an indicator is provided for the type of tool. The valuation classes chosen there were not adopted for the optimised scoring system. An essential difference is that in the standard so-called basic tools are defined. If these tools are required, the evaluation class A is reached, while other commercially available tools lead to evaluation class B. Such a small-scale assessment of tools is not considered useful. For one thing, no clear data is available on the actual commonness of tools. For another, the case studies have shown that in the vast majority of cases operations can be performed with different tools (e. g., with a slotted screwdriver or with lever tools (of different designs) or with a chip card, etc.). If the assessment classes are chosen as in the standard, it would have to be clarified for each operation whether it can also be performed with a class A tool. There may also be cases where this is disputed or unclear. For dismantling snap rings, for example, it is reasonable and intended to use snap ring pliers. Nevertheless, in many cases dismantling is also possible with a slotted screwdriver or ply bar. The risk of damaging the snap ring may be higher in the second case. In order to avoid such detailed questions, the approach chosen here is that assessment class B is only awarded if a repair operation requires a tool that can only be obtained by a competent repairer.

Guidance for the use and monitoring of the indicator:

Manufacturers must specify a recommended tool for each operation in the repair manual they submit. If the use of a tool that can only be obtained by a competent repairer or authorised service partner is unavoidable, this must be indicated.

5.1.4 Detachability of side panels

The indicator detachability of side panels assesses how many side panels of a device (dryer) can be removed without first removing another side panel.

This indicator is not derived from existing approaches to assess repairability (see chapter 3), but, is derived from the case studies conducted in this project. The studies have shown that dryer models in which as many side panels as possible can be detached independently of all other side panels have lower disassembly times and depths in the sum of all priority parts.

If, for example, the right-hand side panel of a device is to be removed in order to reach the motor capacitors, it is unfavourable if the front panel has to be removed first in order to be able to remove the right-hand side panel afterwards. Devices where the right-hand side panel can be removed directly, on the other hand, will have a lower disassembly time and depth in relation to the motor capacitors. Being able to remove the side panels independently of each other is particularly important in practice when the space situation at the customer's site is tight. In confined spaces, it is more difficult to orient dryers several times so that all side panels that need to be removed can be easily reached.

The detachability of side panels is assessed at device level. The selected valuation classes and the point scale for the indicator detachability of side panels are shown in Table 57 below. The point scale starts with zero points if only one side panel can be detached independently of the others, as this case is always achieved by all dryer models due to their design.

Table 57: Indicator detachability of side panels

Indicator	Assessment level	Valuation classes	Point scale
Detachability of side panels	Device	A: Four panels of the tumble dryer can be removed independently of all other panels. B: Three panels of the tumble dryer can be removed independently of all other panels. C: Two panels of the tumble dryer can be removed independently of all other panels. D: One panel of the tumble dryer can be removed independently of all other panels.	A = 10 B = 7 C = 4 D = 1

Source: Own depiction

The indicator detachability of the side panels is to be seen as a product-specific indicator for dryers. It can be assumed that it can be transferred to (large) household devices that are similar to tumble dryers in their basic design, e. g., washing machines or dishwashers. According to current knowledge, however, the application of the indicator only makes sense for product groups that have clearly defined side panels. This is not the case with printers, for example. In many cases, they do not consist of housing parts that can be clearly designated as right side panel, left side panel, etc. Notes on the application and monitoring of the indicator:

For the purpose of this indicator, the right and left side panel, the front panel and the rear panel of the dryer are considered to be a side panel. The dryer lid is not considered a side panel. Dryer lids usually have to be removed from dryer models commonly used in Europe, before a side panel can be removed. As previously described, manufacturers must provide repair manuals to a monitoring body that outline the intended steps for disassembly of each priority part. The repair manuals shall indicate how many side panels can be removed independently of all other side panels.

5.2 Indicators that follow from research

5.2.1 Manufacturer’s spare parts policy

The indicator manufacturer's spare parts policy assesses whether manufacturers exclude certain types of spare parts from being available to certain target groups. The indicator is not derived from one of the existing approaches to assessing repairability summarised in chapter 3, but is based on the results of the case studies. In the case studies, it was noticed that some manufacturers do not make so-called safety-relevant spare parts available to lay persons or even to professional repairer. It was striking, that in many cases no definition of a safety-relevant part was given. In several cases, all “internal” parts were included. For the application of the indicator, it is suggested that the parts that are operated with a voltage of 220 V can be considered safety-relevant.

The manufacturer's spare parts policy is assessed at the device level, as it is usually consistent at least at the model level. In many cases, a manufacturer even follows the same spare parts policy for all devices of a product group. Table 58 below shows the assessment classes and the point scale for the indicator.

The manufacturer's spare parts policy is assessed at the device level, as it is not a question of the availability of each part, but rather of a global statement as to whether all parts are made available or an entire group is excluded. The policy of making all parts available to all target groups is the most customer-friendly and therefore receives the highest score (10 points). In order not to completely dismiss the argument of safety relevance, especially for lay persons, 5 points are awarded for the case that the policy is that at least the non-safety relevant spare parts are made available.

When calculating the partial utility score for manufacturer's spare parts policy, the sum of the achieved scores for lay persons, professional repairer and contractors is divided by the maximum achievable score. In this case, the maximum achievable score is 30 (3*10) (see also chapter 6.2).

Table 58: Indicator manufacturer’s spare parts policy

Indicator	Assessment level	Valuation classes	Point scale
Manufacturer’s spare parts policy for the model	Device	For lay persons A: Non-safety-relevant spare parts and safety-relevant spare parts are available B: Only non-safety-relevant spare parts are available C: No spare parts are available For professional repairers: A: Non-safety related spare parts and safety related spare parts are available B: Only non-safety related spare parts are available C: No spare parts are available For authorised service partners of the manufacturer / the manufacturer: A: Non-safety related spare parts and safety related spare parts are available B: Only non-safety related spare parts are available C: No spare parts are available	A = 10 B = 5 C = 0 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0

Source: Own depiction

Guidance for the application and monitoring of the indicator:

For an effective assessment, a manufacturer should provide information on its spare parts policy per target group to a monitoring body.

5.2.2 Availability of spare parts

The indicator “availability of spare parts” assesses whether priority parts can be obtained as spare parts by each target group. Unavailable spare parts can severely limit the repairability of devices. The case studies have shown that not all spare parts are available and that some manufacturer's strategies are more customer-friendly than others. The indicator is therefore of great importance.

The availability of spare parts is differentiated for the three target groups considered in the project (private individuals, competent repairers and authorised service partners/manufacturers).

The availability of the spare parts is assessed at part level, i. e., for each spare part individually. Therefore, when calculating the partial utility score “availability of spare parts”, the sum of the achieved scores is divided by the maximum achievable score (see also chapter 6.2).

The indicator is also proposed in the example of a scoring system in the EN 45554 standard. The valuation classes presented here are based on those of the standard.

In this indicator, the availability of spare parts is initially assessed as independently as possible from other aspects such as spare parts costs, delivery times, etc. For these aspects, further indicators follow. How indicators that relate to one topic (here: spare parts) can mathematically be calculated as independently of each other as possible is addressed in the chapter 6.2.

Table 59 below shows the valuation classes and the point scale for the indicator. If a spare part is not available and therefore cannot be replaced, zero points are awarded.

Table 59: Indicator availability of spare parts

Indicator	Assessment level	Valuation classes	Point scale
Availability of spare parts	Parts	A: The spare part is available for lay persons, professional repairers and authorised service partners/manufacturers B: The spare part is available for professional repairer and authorised service partners/manufacturers. C: The spare part is only available for authorised service partners/manufacturers. D: The spare part is not available	A = 10 B = 7 C = 3 D = 0

Source: Own depiction

Concerning the availability of spare parts, the case studies have shown that searching and ordering via a website or asking a good customer service is equally effective. This indicator therefore does not assess where or how something is made available.

Guidance for the use and monitoring of the indicator:

For an effective assessment, the manufacturer should define to a monitoring body for which target group (lay persons, competent repairers, authorised service partners/manufacturers) which priority parts are made available as spare parts. The information is given at the time of the first placing on the market of a device. The aspect of how long the spare part is made available is evaluated in the indicator “Duration of availability of spare parts” (see following chapter 5.2.3).

5.2.3 Duration of availability of spare parts

The indicator "duration of availability of spare parts" assesses the period for which the availability of those parts that the manufacturer provides for a target group is promised.

An indicator "duration of availability of spare parts" is also part of the example for a scoring system in the standard EN 45554. There the evaluation classes short-term, medium-term and long-term availability are proposed. The specification of the classes is left to the user of the document. Likewise, it is left to the user to decide which period should be assessed (e. g., period after the market launch of a product, period after the sale of a product, etc.).

During the case studies it was found that the duration of the availability of spare parts is handled very flexibly (in terms of time) by many manufacturers. It depends, for example, on the (current) sales figures of individual models. This flexibility occurs especially with printers. In contrast, other manufacturers state that spare parts they make available remain available for minimum periods of several years.

Due to the flexible handling of spare parts availability by manufacturers, the manufacturer's commitment should be assessed in the indicator, as the actual availability on the market can change weekly and the repairability of devices would always have to be reassessed. The principle of following a manufacturer's statement is in line with the approach proposed for the indicator system in the EN 45554 standard. The manufacturer's commitment must include the target groups for which the manufacturer has defined spare parts as available (see chapter 5.2.1) and should be valid for a period after the last device has been placed on the market. For example, if a manufacturer states that feed rollers are available for a printer model for lay persons, this is first assessed in the indicator "availability of spare parts".

Secondly, in the indicator "duration of availability of spare parts", points can be scored if the manufacturer promises that the availability of this part for lay persons will be maintained for a minimum period of years after the last device has been placed on the market. If no commitment is made, no points can be scored in this indicator.

Valuation classes are formed in accordance with the results of the practical investigations. The classes (short-, medium-, long-term) from the EN 45554 standard seem to make sense and are therefore adopted. However, based on the results of the case studies, concrete time frames are also proposed for printers and dryers. The time periods are chosen differently in order to take into account the generally faster technical progress in information technology (see Table 60). It is assumed that the valuation classes can be transferred to several other product groups of major household appliances and information technology.

In the optimised scoring system, the start of the period for which the availability of spare parts must be promised is chosen as the placing on the market of the last model, since this last device must also be repairable.

The indicator is assessed at the device level, as commitments by manufacturers are usually made for at least one model and in many cases for all models of a manufacturer. Table 60 below shows the valuation classes and the point scale for the indicator.

Table 60: Indicator duration of availability of spare parts

Indicator	Assessment level	Valuation classes	Point scale
Duration of availability of spare parts	Device	A: Long-term availability (≥ 10 years for printers and ≥ 15 years for dryers after placing the last unit of a product model on the market) B: Medium-term availability (> 2 to < 10 years for printers and > 2 to < 15 years for dryers, after placing the last unit of a product model on the market) C: Short-term availability or no availability (≤ 2 years for printers as well as dryers after placing the last unit of a product model on the market)	A = 10 B = 5 C = 0

Source: Own depiction

Guidance on the application and monitoring of the indicator:

As described above, this indicator assesses the manufacturer's commitment to the availability of spare parts for a model. For an effective assessment, the manufacturer should therefore promise or not promise a minimum period of availability of spare parts to a monitoring body.

5.2.4 Delivery time for spare parts

This indicator assesses how quickly spare parts are made available by the manufacturer. This aspect is assessed, as an extremely long delivery time of several weeks means that the spare part is in fact not available and a repair is prevented. Very long delivery times occurred occasionally in the case studies.

The delivery time of spare parts is not proposed as an indicator in the example of a scoring system in the EN 45554 standard. Regarding the availability of spare parts, it is stated: "When establishing product-specific assessment procedures, the user of this document may take into account the aspect of delivery time of spare parts, if appropriate".

Analogous to the duration of the availability of spare parts, the optimised scoring system assesses commitment from the manufacturer. It makes sense that the commitment should refer to the time span between the receipt of the order and the time when the spare part leaves the manufacturer's or a service provider's warehouse. This precludes difficulties at external logistics service providers from influencing the assessment of devices. In order to limit the administrative burden of the indicator, which is already assessed at part level, there is no classification by target group. The case studies have shown that delivery times do not differ for lay persons or professional repairers.

For the optimised scoring system, the principle of assessing indicators independently is applied wherever possible. For the delivery time of spare parts, this means that the delivery time of a part that is not available is not included in the assessment. This is to prevent a doubly negative assessment of an issue. How this is mathematically implemented in the application of the scoring system is explained in chapter 6.2.

The indicator is evaluated at the part level, as the case studies revealed large differences in the delivery time of different spare parts. Table 61 below shows the valuation classes and the point scale for the indicator. One point is awarded for valuation class D, as a spare part that can be delivered after a long time is still available. The distances for the valuation classes were chosen to reflect ranges for the devices that were part of the case studies.

Table 61: Indicator delivery time for spare parts

Indicator	Assessment level	Valuation classes	Point scale
Delivery time for spare parts	Parts	A: ≤ 4 working days B: 5 to 14 working days C: 15 to 21 working days D: ≥ 22 working days	A = 10 B = 7 C = 4 D = 1

Source: Own depiction

Guidance on the use and monitoring of the indicator:

As described above, this indicator assesses the manufacturer's commitment to the delivery time of spare parts. For an effective assessment, the manufacturer should therefore promise a time period per part after it leaves the warehouse to a monitoring body. This applies to the spare parts that have been defined as available for at least one target group. If the manufacturer does not make a commitment for the delivery time, the worst valuation class is assumed.

5.2.5 Costs for spare parts

The indicator "cost of spare parts" assesses the cost of spare parts made available. In the context of the case studies, some parts occurred whose spare parts price was almost as high as the price for the entire device. In practice, such costs can lead to spare parts only being theoretically available and repairs not being carried out.

The indicator "cost of spare parts" is not included in the example of a scoring system of the EN45554 standard. However, the case studies have shown that there is a wide range of costs for spare parts. Therefore, such an indicator should be assessed in terms of repairability. This is also implemented, for example, in the French Repair Index (see chapter 3.2.1). In this case, spare parts costs are evaluated as a percentage of the appliance price. This approach was also chosen here.

Just like the availability of spare parts, the costs of spare parts could also be flexible in time. Therefore, the manufacturer's promise that a spare part will be available up to a certain maximum price is assessed. The promise must be valid for the duration of availability that the manufacturer promises.

The case studies have shown that spare parts are made available in different designs and complexities. In this context, it is usually the case that individual spare parts are less expensive than assemblies. From an environmental point of view, the replacement of individual components usually requires less resources than the replacement of assemblies. However, the exchange of an assembly group may be easier for lay persons in many cases, whereas the exchange of individual components would be much more difficult. Assemblies therefore make repairs more resource-intensive and expensive but simpler in many cases.

To reflect the fact that more complex spare parts (i. e., assemblies) require more material input and can cost more than simple spare parts (e. g., seals), the indicator is broken down into three spare part classes. These are defined as follows:

1. **assemblies** are composed of several individual parts or components to fulfil a specific function (DIN EN ISO 10209:2012; ISO 7573:2008; Neudörfer 2005).

2. assemblies can themselves also consist of sub-assemblies (Pahl/Beitz 1993), these are referred to in this project as **subassemblies** (DIN 199-3:1978).

3. **components** are individual parts that cannot be further disassembled without losing fundamental properties (DIN EN ISO 10209:2012; ISO 14617-1:2005).

As with the delivery time of spare parts, the aim is again to assess indicators as independently as possible. Therefore, only costs of spare parts that are available for at least one target group are included in the assessment. For the mathematical implementation see chapter 6.2. An additional breakdown by target groups is not made, as the case studies did not show any price deviations between target groups.

The costs of spare parts are assessed at part level. Table 62 below shows the valuation classes and the point scale for the indicator. For valuation class C, one point is awarded because a very expensive spare part is still available. The intervals for the valuation classes were chosen to reflect ranges in the devices that were part of the case studies.

Table 62: Indicator cost of spare parts / valuation classes

Indicator	Assessment level	Valuation classes	Point scale
Cost of spare parts	Parts	Assemblies: A: ≤ 20% of the RRP of the product at the time the device was placed on the market B: > 20 to < 50% of the RRP of the product at the time the device was placed on the market C: ≥ 50% of the RRP of the product at the time the device was placed on the market	A = 10 B = 5 C = 1
		Subassemblies: A: ≤ 10% of the RRP of the product at the time the device was placed on the market B: > 10 to < 20% of the RRP of the product at the time the device was placed on the market C: ≥ 20% of the RRP of the product at the time the device was placed on the market	A = 10 B = 5 C = 1
		Components: A: ≤ 5% of the RRP of the product at the time the device was placed on the market B: > 5 to < 10% of the RRP of the product at the time the device was placed on the market C: ≥ 10% of the RRP of the product at the time the device was placed on the market	A = 10 B = 5 C = 1

Source: Own depiction

Guidance on the use and monitoring of the indicator:

As described above, this indicator assesses the manufacturer's commitment to the cost of spare parts. For an effective assessment, the manufacturer should therefore promise to a monitoring body that a spare part will be available up to a maximum price. This applies to the spare parts defined by the manufacturer as available for at least one target group. The commitment shall be valid for the period for which the manufacturer commits to the availability of the spare part. If a manufacturer does not make a commitment, the worst valuation class is assumed.

5.2.6 Availability of information

The indicator assesses whether and for whom repair information is provided by manufacturers. The case studies have shown that such information can simplify the repair process.

The availability of information is included as an indicator in the example of a scoring system in the EN 45554 standard. There, on the one hand, the type of information available is assessed. Basic, comprehensive and no information are proposed as valuation classes. The terms are not elaborated in the horizontal standard. Therefore, it is up to the user to define what basic or comprehensive information is. Furthermore, the standard assesses for which target group the information is available.

The basic approaches from the standard are adopted for the optimised scoring system (see Table 63). The valuation classes are defined on the basis of the case studies. Exploded views, error code tables and circuit diagrams are defined as basic information, as these can be used in particular to make the decision to repair. If repair instructions are additionally provided, this is rated as comprehensive information. A valuation class is achieved if the two required pieces of information are available. Thus, to reach class A, basic and comprehensive information must be provided.

The indicator is subdivided according to the target groups considered in the project and is evaluated at device level. Table 63 below shows the valuation classes and point scale for the indicator. Zero points are awarded if the basic information is not made available.

Table 63: Indicator availability of information

Indicator	Assessment level	Valuation classes	Point scale
Availability of information	Device	For lay persons: A: Comprehensive information is available B: Basic information is available C: No information is available For professional repairers: A: Comprehensive information is available B: Basic information is available C: No information is available For authorised service partners of the manufacturer / the manufacturer: A: Comprehensive information is available B: Basic information is available C: No information is available	 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0 A = 10 B = 5 C = 0

Source: Own depiction

Guidance for the application and monitoring of the indicator:

For an effective assessment, the manufacturer should define towards a monitoring body for which target group (lay persons, competent repairers, authorised service partners / manufacturers) which information will be made available. The availability of information must be defined and promised for the same duration for which the manufacturer promises the availability of spare parts (see chapter 5.2.3). If a manufacturer does not make a statement on the availability of information, the worst valuation class is assumed.

With regard to the error code tables, it is evaluated whether they are made available. The scope is not evaluated, as no objective measure for the quality of the error code table could be derived from the case studies. The exploded view must clearly identify the priority parts, including the location where they are installed in the equipment. Accompanying information shall include unique part numbers. Circuit diagrams shall show the voltage that must be applied to priority parts during fault-free operation and the amperage that the part must accept. Repair manuals shall indicate the proposed steps to remove the priority parts, including the types of fasteners to be disconnected. If a tool, that cannot be freely purchased commercially by all target groups, is required to perform an operation this shall be indicated.

With regard to the error code tables, it must be noted that the availability must be assessed in conjunction with the assessment of the diagnostic interface. If a device achieves valuation class A (intuitive interface) for the diagnostic interface, the error code table is considered available.

5.2.7 Diagnostic interface

The indicator assesses how a device communicates possible errors or how these can be read out. According to the results of the case studies, at least intuitive and coded user interfaces, non-proprietary and proprietary data interfaces should be mapped as valuation classes.

Diagnostic support and interfaces are included as an indicator in the example of a scoring system in the EN 45554 standard. The valuation classes presented there map the results of the case studies well and are therefore adopted for the optimised scoring system for repairability (see Table 64).

The indicator is assessed at device level. Table 64 below shows the valuation classes and point scale for the indicator. If a device has more than one interface, the best valuation class achieved is scored.

Table 64: Indicator diagnostic interface

Indicator	Assessment level	Valuation classes	Point scale
Diagnostic interface	Device	A: Intuitive interface: Error is communicated with a signal that is understood without external accompanying documentation.	A = 10
		B: Coded interface with public reference table: Error can be read out via interface in conjunction with supplied or publicly available accompanying documentation, (e. g., error code table).	B = 7
		C: Publicly available hardware/software interface: Publicly available hardware and/or software is required to read out the error.	C = 4
		D: Proprietary interface: To read out the error, proprietary hardware and/or software is required and / or is not supplied with the product.	D = 1
		E: Not possible with any interface type.	E = 0

Source: Own depiction

Guidance on the use and monitoring of the indicator:

For an effective assessment, information on diagnostic interfaces should be provided by the manufacturer to a monitoring body. The case studies have shown that this information is contained in the operating manual of devices. It is therefore usually sufficient to provide the operating manual to a monitoring body.

5.2.8 Duration of availability of updated software and firmware

The indicator assesses the period for which the availability of updated software and firmware is promised by the manufacturer. In this context, updated means that the manufacturer promises that the software / firmware will be adapted to new conditions, such as new operating systems, for a number of years. The case studies showed that the availability of software and firmware was the decisive criterion. Other aspects such as costs or delivery times were not relevant, as software could be downloaded free of charge in each case. Therefore, only the availability of updated software and firmware is focused on, in order to limit the administrative effort for an optimised scoring system. However, the adaptation of the matrix for a more detailed assessment of different indicators for software analogous to spare parts is possible if needed.

The aspect of software and firmware is considered in the example of a scoring system in the EN 45554 standard. The approach chosen there is that software can be considered a spare part and is covered with the spare parts via their indicators.

In the optimised scoring system presented here, software and firmware are evaluated in a separate indicator to cover the aspect of updating. For software it does not just matter if a driver is available for download on the internet for a number of years, for example. It does matter that an offered driver will be updated for a number of years and will be compatible with operating systems that are newly placed on the market within this number of years.

The indicator is assessed at device level and subdivided into the points software (here driver) and firmware. The point driver may only be relevant for information technology devices (here printers). Table 65 below shows the valuation classes and point scale for the driver and firmware indicator.

Table 65: Indicator duration of availability of updated software and firmware

Indicator	Assessment level	Valuation classes	Point scale
Firmware	Device	A: Updated firmware provided for ≥ 10 years for printers and ≥ 15 years for dryers after the placing on the market of the last unit of a product model	A = 10
		B: Updated firmware provided for > 2 to < 10 years for printers and > 2 to < 15 years for dryers after the placing on the market of the last unit of a product model	B = 5
		C: Updated firmware provided ≤ 2 years for printers as well as for dryers after the placing on the market of the last unit of a product model	C = 0

Indicator	Assessment level	Valuation classes	Point scale
Driver (Only for printers)	Device	A: Updated driver provided for ≥ 10 years for all relevant operating systems after the last model was placed on the market (Windows, macOS, Linux) B: Updated driver provided for ≥ 10 years for all originally supported operating systems after the last model was placed on the market. C: Updated driver provided < 10 years after the last model was placed on the market	A = 10 B = 5 C = 0

Source: Own depiction

Notes on the use and monitoring of the indicator:

As described above, this indicator assesses the manufacturer's commitment to the availability of updated firmware and drivers. For an effective assessment, the manufacturer must therefore promise or not promise a minimum period of availability to a monitoring body. If no commitment is made, the worst valuation class is achieved.

5.2.9 Restoring the factory settings

The indicator assesses whether and how a device can be returned to its delivery condition. The indicator is usually only relevant for electronic devices (here: printers).

Restoring the factory settings is an indicator that is included in the example of a scoring system in the EN 45554 standard. The four valuation classes presented there cover the possibilities for resetting to factory settings and are therefore adopted analogously.

The indicator is evaluated at device level. Table 66 below shows the valuation classes and point scale for the indicator. If a reset is not possible, zero points are awarded.

Table 66: Indicator restoring the factory settings

Indicator	Assessment level	Valuation classes	Point scale
Restoring the factory settings and resetting passwords (Just for printers)	Device	A: Restoring factory settings and resetting passwords is possible with the help of a function integrated in the device B: Restoration of factory settings and resetting of passwords is possible with the help of freely accessible hardware or software C: Restoration of factory settings and resetting of passwords is only possible with the help of the manufacturer's authorised service partners / the manufacturer (service reset) D: Restoration of factory settings and resetting of passwords is not possible	A = 10 B = 5 C = 1 D = 0

Source: Own depiction

Notes on the use and monitoring of the indicator:

For an effective assessment, information on resetting to factory settings should be provided by the manufacturer to a monitoring body. The case studies have shown that this information is contained in the operating instructions of equipment. It is therefore usually sufficient to provide the operating instructions to a monitoring body.

6 Exemplary assessment of selected printers and dryers using the optimised scoring system for repairability

In this chapter, the optimised scoring system (see chapter 5) is tested for its suitability on two printers and two dryers. On the one hand, the evaluation of the devices demonstrates, by way of example, that the optimised scoring system can be applied. On the other hand, this procedure verifies whether the optimised scoring system generates scores that seem reasonable according to the results of the case studies. Devices that were part of the case studies were selected to test the optimised scoring system.

6.1 Selection of devices

To test the optimised scoring system on the printers, two devices from the same manufacturer were selected: the LP3 and LP4 laser printers from manufacturer 3. The results of the case study have shown that the devices are relatively similar (e. g., in the indicator spare parts availability). Therefore, it was expected that the two printers would achieve scores that were relatively close to each other when applying the optimised scoring system. The printers were selected in this way to check whether this is indeed the case. (See chapter 6.3 for the result).

For testing the optimised scoring system on the dryers, HPD1 (manufacturer 1) and HPD8 (manufacturer 5), two heat pump dryers from different manufacturers, were selected. The case studies have shown that the two devices differ comparatively strongly from each other with regard to many indicators. HPD1, for example, has the second lowest disassembly time (02:36:40). In contrast, HPD8 has the highest disassembly time of all heat pump dryers in the case study (05:08:30). Furthermore, manufacturer 1 offers very good spare parts availability and manufacturer 5 offers limited spare parts availability. Therefore, it was expected that manufacturer 1's HPD1 would score better than manufacturer 5's HPD8 heat pump dryer. Furthermore, it was expected that the scores of the two dryers would be further apart than the scores of the two printers after applying the optimised scoring system. The devices were selected in this way to check whether the expected results became true. (For the result see chapter 6.3.)

6.2 Scoring system for repairability in the form of a utility analysis

Indicators, valuation classes and the point scale of the optimised scoring system for repairability are presented in chapter 5. After applying the scoring system, a numerical score for the repairability of an assessed device is generated. This total score is composed of sub-score values for the individual indicators that are important for the repairability of a device.

In order to calculate numerical sub-score values and to add these up appropriately to the total score, the instrument of a utility analysis was selected. The basic procedure is described below.

In this case, as described in Chapter 5, the evaluation of some indicators takes place at the device level and other indicators at the part level. In both cases, partial utilities can be calculated for the indicators.

An example for the evaluation of an indicator on device level is the indicator fault diagnosis. The best valuation class that can be achieved is valuation class A. The valuation class A corresponds to ten points. If a printer achieves a valuation class B for the indicator, it is awarded seven out of ten points. To calculate the partial utility for the indicator, the number of points achieved by a device is divided by the maximum number of points that can be achieved. This value is then multiplied by a factor of 10. This ensures that each partial benefit lies between one and ten and can be grasped more quickly by users. For example, a printer that achieves a B on the fault diagnosis indicator has a partial benefit of 7 / 10 * 10 = 7.

The method to calculate the partial utility remains the same, even if an indicator is not evaluated at device level but at part level. An example of an indicator that is evaluated at part level is the spare parts availability.

In the case of laser printers, for example, nine priority parts, i. e., also nine spare parts, were considered. For each spare part, a valuation class is achieved. The best valuation class A is assigned ten points. The maximum achievable score for spare parts availability is therefore 9 * 10 = 90 points. If, for example, the valuation class A is reached eight times for a printer, but one spare part is not available (corresponds to zero points), this printer achieves 80 of 90 possible points. The partial utility for spare part availability is 80 / 90 * 10 = 8.89.

In addition to the described basic principles for calculating the partial utility scores there are some particularities in the utility analysis carried out. For example, it was already described in Chapter 5 that the indicators should be evaluated independently of each other, if possible. This is implemented with the help of the utility analysis. An example of this is the indicator “delivery time for spare parts”. For this indicator, only the delivery times for spare parts that are actually available are included in the partial utility. The best valuation class A also corresponds to ten points here. If, for example, eight out of nine spare parts are available for a laser printer, but one spare part is not available, then the maximum achievable score for the indicator delivery time is 8 * 10 = 80 points and not 90 points. The point value achieved is therefore divided by 80 and then multiplied by ten to obtain the partial utility.

In this way, an assessed device will not receive zero points for an infinitely long delivery time, if a spare part is not available. This makes sense because an unavailable spare part is already given zero points for the indicator “spare part availability”. To award zero points again for the indicator “delivery time” would be a doubly negative evaluation of the same fact. Therefore, the indicator “delivery time” only assesses how quickly those spare parts can be delivered that are actually available. The same principle is applied to the indicator “cost of spare parts”.

Another special feature of the utility analysis is that some indicators are subdivided into several categories. For example, some indicators are evaluated per target group (lay persons, professional repairers, authorised service partners). An example of an indicator broken down by target group is the indicator “manufacturer's spare parts policy”. This indicator is assessed at device level. Ten points are assigned to valuation class A, regardless of the target group. For valuation classes B and C, five points or zero points are assigned. In the evaluation, a device achieves one valuation class for each target group. The maximum achievable point value for the indicator is therefore 3 * 10 = 30. If a device achieves ten points because safety-relevant spare parts are only available to authorised service partners, then this achieved point value is divided by the maximum achievable point value and then multiplied by a factor of ten to obtain the partial utility for the indicator: 10 / 30 * 10 = 3.33. The same principle of subdividing an indicator is also applied to the indicator “cost of spare parts”.

The partial utilities for each indicator, calculated according to the basic principles and special features presented, are then combined into a utility score per device. As is usual in utility analysis, the partial utilities are first converted into weighted partial utilities. To do this, the partial utilities are multiplied by a percentage. The sum of all percentages by which the partial utilities are multiplied must be 100% (see Table 67 and Table 68). This approach has the advantage that the utility score (here: repairability score) always lies between one and ten and can be quickly understood by users. Furthermore, indicators can be assigned a different weight. A higher utility value means that a device is more repairable.

6.3 Results of the assessment

As described, two laser printers and two heat pump dryers were evaluated using the optimised scoring system for repairability in combination with the utility analysis tool described above. The complete utility analyses are presented in Appendix C.

The following Table 67 shows the partial utilities and the weighted partial utilities of all indicators as well as the utility scores (sum of the weighted partial utilities) of the laser printers LP3 and LP4 of manufacturer 3.

Table 67: Comparison of utility scores, printers

Indicators	Weight assigned	Partial utility Skala 1 – 10 MF3, LP3	Partial utility Skala 1 – 10 MF3, LP4	Weighted Partial utility MF3, LP3	Weighted Partial utility MF3, LP4
Fault diagnosis	8.33%	10.00	10.00	0.83	0.83
Availability of information	8.33%	3.33	3.33	0.28	0.28
Manufacturer's spare parts policy	8.33%	10.00	10.00	0.83	0.83
Availability of spare parts	8.33%	8.89	8.89	0.74	0.74
Duration of availability of spare parts	8.33%	0.00	0.00	0.00	0.00
Delivery time for spare parts	8.33%	7.00	7.75	0.58	0.65
Costs for spare parts	8.33%	3.75	3.75	0.31	0.31
Fastener type	8.33%	10.00	10.00	0.83	0.83
Tool type	8.33%	10.00	10.00	0.83	0.83
Restoring the factory settings and resetting passwords	8.33%	10.00	10.00	0.83	0.83
Software	8.33%	0.00	0.00	0.00	0.00
Disassembly depth	8.33%	3.33	2.44	0.28	0.20
Sum	**100.00%**			**6.34**	**6.33**

Source: Own depiciton

As can be seen in the column "weight assigned", all indicators were weighted equally. However, it would also be possible to give some indicators a stronger weight.

The calculated utility score of the printer LP3 of manufacturer 3 is 6.34 and the utility score for the printer LP4 of manufacturer 3 is 6.33. These utility scores are very close to each other.

Thus, the result is in line with the expectation that these two similar printers by the same manufacturer would achieve scores that are relatively close to each other when applying the scoring system (see chapter 6.2).

The partial utilities of the two laser printers are identical for most indicators. The only exceptions are the indicators “delivery time for spare parts” and “disassembly depth”. Here, the two laser printers examined achieve different partial utilities. The LP3 performs slightly better than the LP4 in terms of disassembly depth. This result agrees well with the results of the case study. On the other hand, the LP4 has a shorter delivery time for spare parts than the LP3. The differences in these two partial utilities almost balance each other out when the utility scores for the two devices are calculated, so that the resulting utility scores are close together.

The following Table 68 shows the partial utilities and the weighted partial utilities of all indicators as well as the utility scores (sum of the weighted partial utilities) of the heat pump dryers HPD1 of manufacturer 1 and HPD8 of manufacturer 5.

Table 68: Comparison of utility scores, heat pump dryers

Indicators	Weight assigned	Partial utility Skala 1 – 10 MF1, HPD1	Partial utility Skala 1 – 10 MF5, HPD8	Weighted Partial utility MF1, HPD1	Weighted Partial utility MF5, HPD8
Fault diagnosis	8.33%	7.00	7.00	0.58	0.58
Availability of information	8.33%	3.33	3.33	0.28	0.28
Manufacturer’s spare parts policy	8.33%	10.00	6.67	0.83	0.56
Availability of spare parts	8.33%	10.00	3.06	0.83	0.25
Duration of availability of spare parts	8.33%	5.00	0.00	0.42	0.00
Delivery time for spare parts	8.33%	9.00	9.63	0.75	0.80
Costs for spare parts	8.33%	9.72	9.69	0.81	0.81
Fastener type	8.33%	10.00	10.00	0.83	0.83
Tool type	8.33%	10.00	10.00	0.83	0.83
Software	8.33%	5.00	0.00	0.42	0.00
Detachability of side panels	8.33%	7.00	4.00	0.58	0.33
Disassembly depth	8.33%	5.19	4.31	0.43	0.36
Sum	**100.00%**			**7.59**	**5.63**

Source: Own depiciton

With a calculated utility score of 7.59, the HPD1 heat pump dryer from manufacturer 1 performs considerably better than the HPD8 heat pump dryer from manufacturer 5, which achieves a utility score of 5.63. The HPD1 achieves a higher partial utility than the HPD8 for almost all indicators. Only for the indicator “delivery time for spare parts” does the HPD8 achieve a slightly better partial utility score. The results for the partial utilities are in line with the results of the case studies, where the HPD1 showed both a lower disassembly time and a customer-friendly spare parts policy.

The result for the heat pump dryers is thus also in line with the expectation that the HPD1 would achieve a better result than the HPD8 when applying the scoring system (see chapter 6.1). It also shows that the difference between the utility scores of the heat pump dryers from different manufacturers is considerably greater than for the laser printers of one manufacturer. This is also in line with expectations (see chapter 6.1).

In this respect, the optimised scoring system for repairability reflects the results of the case studies. It is therefore stated that the scoring system is suitable for assessing the repairability of devices, even without having to carry out practical tests on the devices. The expected differences between the devices are mapped.

When interpreting the results, it should be noted that no weighting of indicators or of spare parts was carried out in assessment presented here. For the laser printers and heat pump dryers, each indicator was equally weighted at 8.3%. (With 12 indicators each, the sum of the weightings is 12 * 8.3% = 100%). It is always possible to assign a higher weighting to an indicator that is considered particularly important. To do this, the weighting (percentage value) of one indicator could be increased and, in return, the weighting (percentage values) of the other indicators could be decreased, as long as the sum of the weightings remains 100%. Following the same principle, it would also be possible to introduce a weighting for spare parts.

7 Measures to strengthen repair

The extent to which a defective product can be repaired depends on a complex web of factors in various dimensions, e. g., technical and informational. To promote repair, these can be deliberately changed with the help of policy instruments. In general, these measures include both hard measures (regulatory, economic) and soft measures (informational, cooperative). First, a review is conducted on how repair is promoted in current key policy programs. Then, based on the key findings of the theoretical and practical work, recommendations for promoting repair are formulated. The focus is on measures that can be integrated into the German waste prevention program and the German resource efficiency program on the one hand, and into the implementing measures of the European Ecodesign Directive on the other. These relate primarily to technical feasibility, taking into account economic viability – without ignoring the relevance of factors in other dimensions.

7.1 Review of current measures to strengthen repairs

The first step is to review the extent to which existing product policy instruments already contain requirements that promote repair. In accordance with the project mandate, the Ecodesign Directive and the corresponding implementing measures will be analyzed at the European level, as well as the Waste Prevention Program (AVP) and the Resource Efficiency Program (ProgRess) at the national level. This will reveal where existing measures need to be made more specific and where entirely new measures need to be taken up to promote repair in the sense of the central study results.

7.1.1 Measures promoting repairs in the German Waste Prevention Program

Article 29 Section 1 of the European Waste Framework Directive (Directive 2008/98/EC) requires member states to develop waste prevention programs. At the national level, the legal basis in accordance with this requirement is found in the German Circular Economy Act (KrWG) in § 33 Section 3. The first German Waste Prevention Program of the federal government with the participation of the federal states was drawn up in 2013. Among other things, it includes concrete measures for waste prevention. However, these measures deal exclusively with waste prevention by the public sector, with individual measures having an indirect or direct impact on various actors, such as consumers or producers. Furthermore, the measures in the waste prevention program only address waste prevention in the legal sense, i. e., any measure taken before a substance, material, or product has become waste and designed to reduce the amount of waste, the harmful effects of the waste on humans and the environment, or the content of harmful substances in materials and products (§ 3 Section 20 KrWG).

So far, the waste prevention program has taken up the measures listed below, which are related to repair in the narrower and broader sense:

Utilization of planning measures or other economic instruments that promote the efficiency of resource use:

- Measure 1: Development of waste prevention concepts and plans by municipalities, e. g., hints on repair shops.

Promotion of eco-design:

- Measure 7: Identification of product-specific requirements for waste-avoiding product design in the context of implementing measures of the EU Ecodesign Directive (2009/125/EC), e. g., possibility of repairing products.

- Measure 8: Disseminate information and increase awareness of waste-avoiding product design, e. g., competition for repair-friendly design.
- Measure 10: Standardization that supports waste-avoiding and resource-efficient product design.
- Measure 27: Use of product labels for resource-saving and thus “waste-avoiding” products.

Encourage reuse and repair of appropriately disposed products:

- Measure 31: Support repair networks, e. g., create quality repair networks.
- Measure 32: Develop quality standards for reuse, e. g., for repair shops.
- Measure 34: Support research and development of life-extending measures, e. g., repair.

The practical implementation of the waste prevention program is to be evaluated every six years and updated if necessary. Accordingly, recommendations for the further development of the waste prevention program were formulated in the course of a project by Wilts et al. (2020). On the one hand, it identifies electrical and electronic equipment as a priority waste stream to be addressed and formulates the following recommendations:

- Disclosure of technical service life and provision of spare parts by manufacturers, open-source solutions, e. g. for 3D printing of spare parts.
- Support of free software and hardware solution.
- Obligation to produce proof for public waste management authorities with their own or external re-use facilities.

On the other hand, repair (and reuse)[11] is formulated as a waste prevention measure to be prioritized, and the following recommendations are formulated to promote it, which also apply to electrical and electronic equipment:

- Support the dissemination of an umbrella brand and quality standards for reuse and repair facilities, including support for the development of insurance packages for repair facilities.
- Enactment of a reduced VAT rate for repair services of small and medium-sized enterprises.
- Support for standardization in the field of repair-friendly products.

The update of the waste prevention programme, which was published in January 2021, was not evaluated in this project.

7.1.2 Measures promoting repair in the German Resource Efficiency Program

The Resource Efficiency Program (ProgRess) is a central component for implementing the German sustainability strategy. It was first implemented in 2012 and is updated every four years. It defines goals, guidelines, and courses of action for the protection of natural resources. Particularly, economic growth is to be decoupled from resource use and the associated environmental impacts reduced. On the other hand, the competitiveness of Germany as a business location is to be strengthened.

[11] For a more extensive overview of field-tested measures to strengthen reuse and their quantitative potentials, see Fischer et. al. (2019).

The Resource Efficiency Program, now in its third version (ProgRess III), defines several fields of action for the years 2020 to 2023, of which the following explicitly relate to strengthening material efficiency through repair, among others:

Extending the useful life of products:

- Measure 19: Investigate non-discriminatory provision of spare parts and design/repair information.
- Measure 20: Develop a rating system for practical repairability as mandatory information (priority measure).
- Reuse and preparation for reuse:
- Measure 50: Support market actors in setting quality standards for testing, cleaning, and repair.

7.1.3 Measures promoting repair in the Ecodesign Directive

The Ecodesign Directive at the European level aims to reduce the environmental impact of energy-related products along their entire life cycle. The directive is implemented in national law by the Energy-Related Products Act (Energieverbrauchsrelevante-Produkte-Gesetz, EVPG). The directive serves as a framework for defining requirements for environmentally friendly product design. Two mechanisms are provided for defining product-specific requirements: Industry self-regulatory initiatives or implementing measures. Requirements for product design are only mandatory once they have been defined in a product-specific implementing measure. The European Commission defines which product groups will be addressed in the future in a corresponding working program.

So far, product-specific measures mainly include energy efficiency requirements, but hardly any resource efficiency requirements. In October and December 2019, implementing measures with specific material efficiency requirements were implemented for the first time, coming into force in March and for light sources in September 2021. They cover the following product groups: Refrigerators, washing machines, washer-dryers, dishwashers, electronic displays (including televisions), light sources and separate operating devices, external power supplies, electric motors, refrigeration equipment with a direct sales function (e. g., vending machines for cold drinks, refrigeration equipment in supermarkets), transformers, and welding equipment. The measures address spare parts, tools and repair instructions:

- Spare parts must be available for between seven or ten years after the last copy of the model is placed on the market, depending on the product group.
- A distinction is made between spare parts that manufacturers must make available to end users and professional repairers and spare parts that manufacturers must make available at least to professional repairers but that can also be supplied to other stakeholders.
- Spare parts must be supplied within fifteen working days after receipt of the order.
- It must be possible to replace spare parts with commonly available tools without permanently damaging the device.
- In the case of spare parts that are also made available to end users, the manufacturer must make the procedures for ordering them and repair instructions available on a freely accessible website of the manufacturer, importer or authorized representative from the time the

first copy of a model is placed on the market until the end of the availability period of these spare parts.

- Professional repairers must be provided with comprehensive repair information, including e. g., an exploded view or disassembly plan, information on components and diagnostics, regardless of whether they are contractual partners of the manufacturers or not.

7.1.4 Concluding considerations

Several policy programs already refer to the need to increase resource efficiency by promoting repair through various measures. Besides the Ecodesign Working Plan (Ökodesign-Arbeitsplan) (2016-2019), the Waste Prevention Program and the Resource Efficiency Program, also the Eco-political Digital Agenda (Umweltpolitische Digitalagenda) (2020), e. g., emphasizes as the first of five measures that products should become more sustainable through binding regulations, e. g., regarding updates, spare parts, the replacement of batteries, displays and other hardware components.

So far, however, these measures have not been specified in detail, and in some cases, there has been a lack of comprehensive, strategically oriented measures to integrate the specific requirements into the political framework. If one considers the entire life cycle of a product, the findings obtained in this project can concretize requirements in the following phases:

- Design phase: repair-friendly product design
- Sales phase: Information for conscious purchasing decisions
- Use phase: conditions favorable to repair.

They are logically interrelated and include economic, technical, and organizational factors. For example, screw connections enable non-destructive repair (production). This is made clear to the customer by means of a label (purchase) and allows simpler repair in the event of a defect (use).

7.2 Recommendation for measures strengthening repair

Based on the preceding theoretical and empirical findings of this project, recommendations for measures to strengthen repair are finally formulated.

7.2.1 Recommendations for updating the standard DIN EN 45554

- The case studies in which the applicability of DIN EN 45554 was tested generally illustrate that the assessment procedure developed in the standard is useful. Specifically, the case studies have clarified the following aspects that should be included in the updating of the standard:

- **Tools:** The standard contains a list of numerous tools that are classified as “basic tools”. They can be used independently of the products to be repaired. However, the case studies have made it clear that the same disassembly step can often be carried out with different tools. For example, a snap ring can be loosened with a pair of snap ring pliers as well as with a slotted screwdriver. However, the risk of damaging the snap ring is lower when using the special pliers. A list, as currently provided for in the standard, could lead to unintentional conflicts of objectives if, for example, manufacturers recommend the use of less suitable tools that are part of the positive list in their repair manuals. It is therefore recommended to only assess in a scoring system whether tools are necessary for the repair that are not available to individual target groups (e. g., lay persons). The list could be revised so that "basic tools" include all tools that are freely available commercially for lay persons. Alternatively, it could be considered to apply a list of "basic tools" only to screws. This would reduce the number of possible conflicts of objectives, as defined types of screwdrivers can usually be assigned to defined screw heads, while click connections can usually be disconnected with a very large number of different lever tools.

- **Working environment:** The working environment required for a repair is difficult to define and the case studies have shown that, at least for printers and dryers, all work could also have been carried out in private households. Therefore, it can be assumed that an indicator "working environment" does not reflect differences between manufacturers for many equipment groups. It is therefore recommended to examine whether this indicator is useful in a further development of the standard. However, it must be ensured that this does not lead to devices no longer being repairable in private households. If necessary, the requirement that repairs must be feasible in private households should be made general in the standard.
- **Knowledge:** The knowledge required for a repair can hardly be evaluated objectively. Many repairs can, at least theoretically, also be carried out by lay persons or less experienced repairers, if it is accepted that the repair will take longer. Which groups of people can carry out repairs can also be mapped in a repairability matrix by evaluating other indicators for differently defined target groups. For example, in the optimised scoring system, indicators are assessed for the three target groups "lay persons, professional repairer and authorised service partners/manufacturers".
- **Return options:** Return options are not necessarily relevant for repair. Consideration should therefore be given to removing this indicator from the standard.
- **Information:** The information available influences the extent to which a repair can be carried out. The case studies show that it is not enough for manufacturers to point out that this information is available at all, rather the standard should ensure that manufacturers make this information available themselves. The standard also does not define what specific information should be available. We recommend that "basic information" should include error code tables, exploded views and circuit diagrams, and "comprehensive information" should also include repair manuals.
- **Work step:** So far, the standard does not clearly define what is meant by a work step. A definition is generally needed before a number of work steps can be used as an indicator or as part of another indicator. In the case studies, the following activities have proven to be practicable to be considered as a work step: (see chapter 4.3): (a) removing of a part, b) unhooking, pulling aside or laying down of a part, c) undoing of a set of screws necessary to proceed to the next step, d) undoing of a set of similar fasteners, which is necessary to move to the next step, e) tilting or angling the device to work on the underside, f)pushing the device to the edge of the work surface to work on the underside.

7.2.2 Recommendations for the revision of the German Waste Avoidance Program and the German Resource Efficiency Program

Numerous options are available to strengthen repair. They can extend the existing measures in the waste prevention programme and the resource efficiency programme when they are updated. Based on the findings in this project, the following proposals are made:

Design phase:

- Revision of the standard DIN EN 45554 in accordance with the proposals in the following chapter 7.2.1.
- Introduction of an implementing regulation for printers to improve repairability and inclusion of repair-relevant indicators in the implementing regulation on tumble dryers in accordance with the recommendations in the following chapter 7.2.3.
- Dissemination of the identified requirements for a repair-friendly product design among manufacturers as well as anchoring of a repair-friendly product design in corresponding courses of study.

Sales phase:

- Inclusion awarding criteria relevant for repair in the Blue Angel in accordance with the proposals in Chapter 7.2.4 below.
- Promoting research projects on consumer behaviour to identify the extent to which a (separate) label for repair makes sense.

Use phase:

- Providing information on the regular maintenance of equipment to prevent defects.
- Providing information so that service companies can be easily found locally.
- Promoting Repair Cafés to overcome the inhibition threshold of lay persons to repair their first device on their own.

7.2.3 Recommendations for the Ecodesign Directive 2009/125/EG

Within the framework of the Ecodesign Directive, requirements for environmentally friendly product design are already formulated in the so-called implementing regulations. It is recommended that further repair-specific minimum requirements, which are a condition for market entry, be included in the corresponding implementing measures, or that they be adapted as follows:

- For tumble dryers, as well as for other large household devices (e. g., washing machines, dishwashers), the side panels must be independently detachable.
- It is considered realistic to reduce the delivery time for spare parts from fifteen to ten days: the spare parts must be delivered within ten working days of receipt of the order.
- For lay persons, at least all non-safety-relevant parts should be provided. In this context, parts that are operated with a voltage of 220 V are considered safety relevant.
- A publicly visible **repairability label** for devices should be promoted, analogous to the energy efficiency label. The repairability label should be based on the indicators and valuation classes of the optimised scoring system for repairability.

The proposed indicators are:

- Disassembly dept,
- Fastener type,
- Tool type,

- Detachability of side panels (for large household equipment),
- Manufacturer's spare parts policy,
- Availability of spare parts,
- Duration of the availability of spare parts,
- Delivery time for spare parts,
- Costs for spare parts,
- Availability of information,
- Fault diagnosis,
- Duration of availability of updated Software and Firmware and
- Restoring of factory settings.

7.2.4 Recommendations for awarding criteria for the Blue Angel

The Blue Angel eco-label should include further requirements for repair-friendly product design in its awarding criteria. Since the Blue Angel is awarded exclusively to environmentally friendly products, it makes sense for these criteria to be based on the indicators developed in the optimised scoring system for repairability and the upper valuation classes. Based on the best valuation class (A), these criteria could, for example, be as follows:

- The number of **steps required** to dismantle tumble dryers and printers must be ≤ 70% of the mean value.
- The **fasteners** used must be reusable.
- Repair must be possible without **tools**, with standard tools commercially available for lay persons or with tools provided.
- The duration of availability of **spare parts** shall be ≥ 10 years for printers and ≥ 15 years for tumble dryers after the placing on the market of the last unit of a product model.
- Spare parts must be available to private individuals, competent repairers and contract partners / manufacturers.
- Non-safety-relevant spare parts and safety-relevant spare parts must be available for private individuals, professional repairers and contract partners / manufacturers.
- **Spare parts** must be delivered within 4 working days.
- Regarding **spare parts prices**, assemblies must cost ≤20% of the RRP of the product at the time the device was placed on the market. Subassemblies must cost ≤10% of the RRP of the product at the time the device was placed on the market. Components must cost ≤5% of the RRP of the product at the time the device was placed on the market.
- Comprehensive **information** shall be available for lay persons, professional repairers and authorised service partners of the manufacturer. Comprehensive information includes error code tables, exploded views, circuit diagrams and repair manuals.

- For **fault diagnosis**, the error must be communicated with a signal that can be understood without external accompanying documents.
- Necessary **firmware** updates must be available for ≥ 10 years for printers and ≥ 15 years for dryers after the placing on the market of the last unit of a product model.
- For printers, it must be possible to **restore factory settings and reset passwords** using the built-in functions of the device.
- For printers, **driver updates** must be provided for all originally supported operating systems for ≥ 10 years after the last model was placed on the market.
- For tumble dryers, each of the four **side panels** must be detachable independent of all other side panels.

It is conceivable to base the Blue Angel award criteria on a potentially revised EN 45554 standard or on a repairability label under the Ecodesign Directive. In such an approach, individual award criteria could either correspond to the best valuation class for individual indicators or valuation classes above the best valuation class could be formulated for the Blue Angel.

8 Further research

This project identified profound theoretical and empirical findings on the repairability of electrical and electronic devices. The results indicate a need for further research.

- The applicability of the **repair matrix** was tested exemplarily for tumble dryers and printers. The findings provide initial key insights into how repairability can be operationalized. However, they have limited validity given the limited number of appliances studied. It is therefore recommended to investigate the applicability for as many different devices in different price ranges as possible to develop a deeper understanding of the extent to which the indicators and assessment classes can be applied horizontally - across different product groups.
- Reference values are required for determining the number of **work steps** that form an indicator of the optimized repair matrix, and these must be determined on a device-specific basis in each case. In this project, they were identified through practical investigations. Based on this, it was exemplarily defined as the best option for tumble dryers and printers that the number of work steps required may be ≤ 70% of the mean value. However, since the underlying reference values are product-specific, it is recommended that further investigations will be carried out for a wide range of products in order to be able to define reference values for other devices and compare them with one another. In addition, serial investigations on product groups should be repeated periodically so that the reference values reflect technical progress.
- The **priority parts** have proven helpful in reducing the complexity associated with a repair. It turns out that the priority parts of a device change from time to time due to technical innovations. For example, in the case of the devices examined, the parts mentioned by repair companies were no longer currently installed in the devices, as was shown during the practical disassemblies. Therefore, it is recommended to periodically investigate which parts are currently present in the appliances on the market to determine the priority parts.
- The predominantly technical aspects developed in this project, e. g., types of fasteners, tools, have a decisive influence on the extent to which a device can be repaired. Hence, they form a necessary prerequisite for a repair. However, it should be noted that not only technical factors generally influence whether a device is repaired, but rather **social factors** also play a role, which are rooted in today's consumer culture, such as the perception of defective devices as worthless. Therefore, it should be analyzed which factors are responsible for the fact that defective devices are rarely repaired nowadays. One may assume that product labeling alone is not enough to encourage consumers to actually repair defective appliances.

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A Additional data for the assessment of devices

In chapter 6 of this report, two laser printers and two heat pump dryers each are assessed as examples using the optimised scoring system for repairability presented in chapter 5.

Much of the information necessary for the assessment was already researched during the case studies for all the devices considered in the project. This information is already presented in chapters 4.4.4 and 4.5.4.

With regard to spare parts (availability, delivery time and costs), however, the consideration in the case studies was limited to a selection of priority parts for some product groups

Therefore, in order to carry out the evaluation of the heat pump dryers, additional information on spare parts had to be obtained for the two devices assessed (HPD1 from manufacturer 1 and the dryer HPD8 from manufacturer 5).

This additional data is listed below. Table 69 shows the additional information on the availability of spare parts. Table 70 shows the costs of spare parts and Table 71 the delivery times for spare parts.

Table 69: Availability of additional spare parts, heat pump dryers

Target Group	HPD1	HPD8
	Door locking nose port	Door locking nose port
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Control board not coded	Control board not coded
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	No
	Control board coded	Control board coded
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Main board not coded	Main board not coded
Lay person	Yes	No

Target Group	HPD1	HPD8
Professional repairer	Yes	No
Authorised service partner	Yes	No
	Main board coded	Main board coded
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Level sensor	Level sensor
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Door lock sensor	Door lock sensor
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Coolant sensor	Coolant sensor
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Rear drum seal	Rear drum seal
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes
	Front drum seal	Front drum seal

Target Group	HPD1	HPD8
Lay person	Yes	No
Professional repairer	Yes	No
Authorised service partner	Yes	Yes

Source: Own depiction

Table 70: Costs of additional spare parts, heat pump dryers

Price	HPD1	HPD8
RRP (€)	889.00	1022.55
	Door locking nose port	Door locking nose port
Costs (€)	12.30	12.29
% of RRP	1.38	1.20
	Control board not coded	Control board not coded
Costs (€)	61.50	n/a
% of RRP	6.92	n/a
	Control board coded	Control board coded
Costs (€)	112.60	66.45
% of RRP	12.67	6.50
	Main board not coded	Main board not coded
Costs (€)	148.96	n/a
% of RRP	16.76	n/a
	Main board coded	Main board coded
Costs (€)	178.96	67.69
% of RRP	20.13	6.62
	Level sensor	Level sensor
Costs (€)	30.45	37.32

Price	HPD1	HPD8
% of RRP	3.43	3.65
	Door lock sensor	Door lock sensor
Costs (€)	5.31	29.04
% of RRP	0.60	2.84
	Coolant sensor	Coolant sensor
Costs (€)	15.95	24.66
% of RRP	1.79	2.41
	Rear drum seal	Rear drum seal
Costs (€)	19.59	49.48
% of RRP	2.20	4.84
	Front drum seal	Front drum seal
Costs (€)	25.16	22.34
% of RRP	2.83	2.19

Source: Own depiction

Table 71: Additional delivery times (in days), heat pump dryers

Spare part	HPD1	HPD8
Door locking nose port	1 - 2	1 - 2
Control board not coded	1 - 2	n/a
Control board coded	14 - 21	1 - 2
Main board not coded	1 - 2	n/a
Main board coded	14 - 21	1 - 2
Level sensor	1 - 2	1 - 2
Door lock sensor	1 - 2	1 - 2
Coolant sensor	1 - 2	1 - 2

Spare part	HPD1	HPD8
Rear drum seal	1 - 2	1 - 2
Front drum seal	1 - 2	1 - 2

Source: Own depiction

B Mean values for the assessment of the disassembly depth

As described in chapter 5.1.1 the percentage deviation from a reference value is used for the evaluation of the indicator disassembly depth.

As reference values for the assessment of two laser printers and two heat pump dryers each, the mean values of the required steps for all laser printers and heat pump dryers examined in the case studies are used for each priority part.

Table 72 below shows the number of steps and mean values to reach the priority parts for laser printers. Table 73 shows the steps and mean values to reach the priority parts for heat pump dryers.

Table 72: Steps for reaching the priority parts, laser printers

Priority part	MF3, LP3	MF3, LP4	MF2, LP1	MF2, LP2	Mean value
Drum unit (DU)	6	5	2	3	4
Feed roller stack sheet feeder (FRSSF)	8	13	3	11	8.75
Transfer roller (TR)	8	9	4	3	6
Paper tray (PT)	26	49	15	51	35.25
Closing lid (CL)	26	24	4	26	20
Laser unit (LU)	42	84	26	66	54.5
Fixing unit (FU)	44	65	33	54	49
Power supply unit (PSU)	25	17	31	30	25.75
Drive motor paper feed (DMPF)	58	25	43	35	40.25

Source: Own depiction

Table 73: Steps for reaching the priority parts, heat pump dryer

Priority part	MF6, HPD10	MF6, HPD9	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5 HPD8	Mean value
Pump (P)	10	10	6	6	21	12	40	40	8	8	16.1
Drum bearing (DB)	9	13	10	10	12	8	36	36	27	28	18.9
Door (D)	3	3	3	3	3	3	3	3	3	3	3

Priority part	MF6, HPD10	MF6, HPD9	MF1, HPD1	MF1, HPD2	MF2, HPD3	MF3, HPD4	MF4, HPD5	MF4, HPD6	MF5, HPD7	MF5 HPD8	Mean value
Door locking nose port (DLN)	44	46	4	5	18	28	3	3	3	3	15.7
Control board (CB)	12	12	12	12	10	11	14	14	16	16	12.9
Main board (MB)	12	12	20	19	17	11	11	11	12	12	13.7
Motor capacitors (MC)	22	16	19	19	20	18	16	16	53	50	24.9
Drum belt (DBT)	37	41	43	42	45	36	36	36	47	46	40.9
Motor (M)	50	54	53	56	34	44	45	45	57	56	49.4
Level sensor (LS)	7	8	6	7	22	12	40	40	8	8	15.8
Humidity sensor (HS)	5	70	8	8	5	6	9	9	52	55	22.7
Door lock sensor (DLS)	44	45	31	25	18	28	15	15	25	19	26.5
Coolant sensor (CS)	15	15	16	16	14	13	12	12	31	24	16.8
Rear drum seal (RDS)	35	41	41	41	43	33	36	36	27	28	36.1
Front drum seal (FDS)	39	42	46	48	46	35	36	36	47	47	42.2
Blower (B)	4	4	20	18	9	4	4	4	5	5	7.7

Source: Own depiction

C Exemplary assessment of selected printers and dryers using the optimised scoring system for repairability

The procedure for the assessment of two selected laser printers and heat pump dryers with the optimised scoring system is described in chapter 6.2. The results (partial utility scores) are presented and discussed in chapter 6.3.

The following tables show the detailed evaluation of all indicators at appliance and part level. Assessment of laser printers LP3 and LP4, manufacturer 3.

C.1 Assessment of laser printers LP3 and LP4, manufacturer 3

Table 74: Assessment manufacturer 3, LP3

Indicator	Target group (TG), Spare part assembly (AB)	MF3, LP3	DU	FRSSF	TR	PT	CL	LU	FU	PSU	DMPF	Points	Max. Poss. points	Partial utility
Fault diagnosis		A										10	10	10
Availability of information	Lay person (LP)	C										0		
Availability of information	Professional repairer (PR)	C										0	30	3.33
Availability of information	Authorised service partner (ASP)	A										10		
Manufacturer's spare parts policy	LP	A										10		
Manufacturer's spare parts policy	PR	A										10	30	10
Manufacturer's spare parts policy	ASP	A										10		

Indicator	Target group (TG), Spare part assembly (AB)	MF3, LP3	DU	FRSSF	TR	PT	CL	LU	FU	PSU	DMPF	Points	Max. Poss. points	Partial utility
Availability spare parts			A	A	A	A	A	A	A	A	D	80	90	8.89
Duration availability spare parts		C										0	10	0
Delivery time spare parts			A	A	B	C	B	C	B	B		56	80	7
Costs of spare parts	Assemblies (AB)							B	C			6		
Costs of spare parts	Subassemblies (SAS)									C		1	80	3.75
Costs of spare parts	Components (CP)		C	A	C	A	C					23		
Fastener type			A	A	A	A	A	A	A	A	A	90	90	10
Tool type			A	A	A	A	A	A	A	A	A	90	90	10
Restoring to factory settings		A										10	10	10
Software	Firmware (FW)	C										0		
Software	Driver (DRV)	C										0	20	0

Indicator	Target group (TG), Spare part assembly (AB)	MF3, LP3	DU	FRSSF	TR	PT	CL	LU	FU	PSU	DMPF	Points	Max. Poss. points	Partial utility
Disassembly depth			E	C	E	B	D	B	B	C	E	30	90	3.33

Source: Own depiction

Table 75: Assessment manufacturer 3, LP4

Indicator	TG, AB	MF3, LP4	DU	FRSSF	TR	PT	CL	LU	FU	PSU	DMPF	Points	Max. Poss. points	Partial utility
Fault diagnosis		A										10	10	10
Availability of information	LP	C										0		
Availability of information	PR	C										0	30	3.33
Availability of information	ASP	A										10		
Manufacturer’s spare parts policy	LP	A										10		
Manufacturer’s spare parts policy	PR	A										10	30	10
Manufacturer’s spare parts policy	ASP	A										10		

Indicator	TG, AB	MF3, LP4	DU	FRSSF	TR	PT	CL	LU	FU	PSU	DMPF	Points	Max. Poss. points	Partial utility
Availability spare parts			A	A	D	A	A	A	A	A	A	80	90	8.89
Durations availability spare parts		C										0	10	0
Delivery time spare parts			A	A		B	B	B	B	B	B	62	80	7.75
Spare parts costs	AB							B	C			6		
Spare parts costs	SAS									C		1	80	3.75
Spare parts costs	CP		C	A		C	C				A	23		
Fastener type			A	A	A	A	A	A	A	A	A	90	90	10
Tool type			A	A	A	A	A	A	A	A	A	90	90	10
Restoring to factory settings		A										10	10	10
Software / Firmware	Firmware (FW)	C										0		
Software / Firmware	Driver (DRV)	C										0	20	0
Disassembly depth			D	E	E	E	D	E	E	A	A	22	90	2.4

Source: Own depiction

C.2 Assessment of heat pump dryers HPD1, manufacturer 1 and HPD8, manufacturer 5

Table 76: Assessment manufacturer 1, HPD1

Indicator	TG, AB	MF 1, HP D1	P	DB	D	DL NP	CB NC	CB C	MB NC	MB C	MC	DB T	M	LS	HS	DLS	CS	RD S	FD S	B	Points	Max. Poss. points	Partial utility
Fault diagnosis		B																			7	10	7
Availability of information	LP	C																			0		
Availability of information	PR	C																			0	30	3.33
Availability of information	ASP	A																			10		
Manufacturer’s spare parts policy	LP	A																			10		
Manufacturer’s spare parts policy	PR	A																			10	30	10
Manufacturer’s spare parts policy	ASP	A																			10		
Availability spare parts			A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	180	180	10

Indicator	TG, AB	MF 1, HP D1	P	DB	D	DL NP	CB NC	CB C	MB NC	MB C	MC	DB T	M	LS	HS	DLS	CS	RD S	FD S	B	Points	Max. Poss. points	Partial utility
Duration availability spare parts		B																			5	10	5
Delivery time spare parts			A	A	A	A	A	C	A	C	A	C	A	A	A	A	A	A	A	A	162	180	9
Spare parts costs	AB				A		A	A	A	B			A								55		
Spare parts costs	SAS		A											A	A	A					40	180	9.72
Spare parts costs	CP			A		A					A	A					A	A	A	A	80		
Fastener type			A	A	A	A		A		A	A	A	A	A	A	A	A	A	A	A	160	160	10
Tool type			A	A	A	A		A		A	A	A	A	A	A	A	A	A	A	A	160	160	10
Restoring to factory settings																					0	10	0
Software / Firmware	FW	A																			10	10	10
Detachability side panels		B																			7	10	7

Indicator	TG, AB	MF 1, HPD1	P	DB	D	DL NP	CB NC	CB C	MB NC	MB C	MC	DBT	M	LS	HS	DLS	CS	RDS	FDS	B	Points	Max. Poss. points	Partial utility
Disassembly depth			A	A	C	A		C		E	B	C	C	A	A	D	C	D	C	E	83	160	5.19

Source: Own depiction

Table 77: Assessment manufacturer 5, HPD8

Indicator	TG, AB	MF5, HPD8	P	DB	D	DL NP	CB NC	CB C	MB NC	MB C	MC	DB T	M	LS	HS	DLS	CS	RDS	FDS	B	Points	Max. Poss. points	Partial utility
Fault diagnosis		B																			7	10	7
Availability of information	LP	C																			0		
Availability of information	PR	C																			0	30	3.33
Availability of information	ASP	A																			10		
Manufacturer’s spare parts policy	LP	B																			5		
Manufacturer’s spare parts policy	PR	B																			5	30	6.67

Indicator	TG, AB	MF5, HPD8	P	DB	D	DL NP	CB NC	CB C	MB NC	MB C	MC	DB T	M	LS	HS	DLS	CS	RD S	FD S	B	Points	Max. Poss. points	Partial utility
Manufacturer's spare parts policy	ASP	A																			10		
Availability spare parts			C	C	A	C	D	C	D	C	C	C	C	C	C	C	C	C	C	C	55	180	3.06
Durations availability spare parts		C																			0	10	0
Delivery time spare parts			A	A	C	A		A		A	A	A	A	A	A	A	A	A	A	A	154	160	9.63
Spare parts costs	AB				B			A		A			A								35		
Spare parts costs	SAS		A											A	A	A					40	160	9.69
Spare parts costs	CP			A		A					A	A					A	A	A	A	80		
Fastener type			A	A	A	A		A		A	A	A	A	A	A	A	A	A	A	A	160	160	10
Tool type			A	A	A	A		A		A	A	A	A	A	A	A	A	A	A	A	160	160	10
restoring to factory settings																					0	10	0
Software / Firmware	FW	C																			0	10	0

Indicator	TG, AB	MF5, HPD8	P	DB	D	DLNP	CBNC	CBC	MBNC	MBC	MC	DBT	M	LS	HS	DLS	CS	RDS	FDS	B	Points	Max. Poss. points	Partial utility
Detachability side panels		C																			4	10	4
Disassembly depth			A	E	C	A		D		B	E	D	D	A	E	B	E	B	D	A	69	160	4.3125

Source: Own depiction