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Leveraging circularity through repair standards: A comparison of methods for assessing product reparability for extended use on mechanical products.

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Abstract

The EN 45554 standard deals with the assessment of Reparability, Reusability and Upgradability of Energy-related Products, and aims to extend the life of those kind of products. According to the 2021 report of the French Agency for Ecological Transition (ADEME), 83% of French people are concerned about the environment. This means a growing interest for repair. In addition, consumers want products that are increasingly repairable. Therefore, knowing the reparability score of any type of products has become crucial, but this standard only applies to products that consume energy during use. Hence, there is a need to extend reparability to a wider range of products, including mechanical and mechatronic products. To achieve this main objective, one important step of comparison of existing methods is necessary. This paper aims to compare the EN 45554 standard to the existing methods in the literature for assessing reparability. First, a literature review is conducted to identify existing methods for reparability. Then, a comparison study is performed. Finally, based on this comparison, a set of criteria is obtained as an outcome.

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Keywords: Reparability; Circular Economy; EN 45554 standard; Energy-related Product; Mechanical product

1. Introduction

The ecological transition is a shift in our thinking towards sustainable thinking. The circular economy, which is one way to make products sustainable, contributes to this transition. To support this circular economy concept, the standard EN 45554 has been established under recommendations from the European Commission and the European Free Trade Association. This standard aims to assess the ability of an Energy-related Product (ErP) to be reused, repaired or upgraded [1]. Nowadays, reparability has become a sort of mindset whose relevance is increasingly confirmed. In fact, according to the

French agency for ecological transition ADEME 2021 report, 83% of French people are concerned about the environment [2]. Therefore, they have a good feeling about the concept of repair, since they prefer to buy a product with a high reparability index. This shows a growing interest in repair. Knowing a score reparability of the product is a key element to ensure service availability and quality. But the EN 45554 and several other methods for assessing reparability only apply to ErP or EEE (Electrical and Electronic Equipment). This is why the reparability of non-ErP should also be addressed. Furthermore, in the context of Industrial Product-Service Systems, controlling product availability has become a key challenge for

design and operation [3]. So, the extension of the EN 45554 standard to mechanical and mechatronic products is necessary to improve the reparability of a wider range of products that getting increasingly circular. However, many methods have been developed in order to study the reparability. It is crucial to compare these methods to determine their strengths, weaknesses, and overall effectiveness in promoting sustainable product design and circular economy principles. This comparative study is the main goal of this paper.

This article is structured as follows: in section 2, the research methodology is described. The results of the overall comparison study between methods for reparability assessment are presented in section 3. The discussion of these results is presented in section 4. Finally, section 5 concludes this paper through a summary and future research work.

| Nomenclature | |
|--------------|---------------------------------------------------------|
| ADEME | French Agency for Ecological Transition |
| AGEC | French law against waste and for Circular Economy |
| AsMer | Assessment Matrix for ease of repair |
| CEN | European Committee for Standardization |
| CENELEC | European Committee for Electrotechnical Standardization |
| EEE | Electrical and Electronic Equipment |
| ErP | Energy-related Product |
| JRC | Joint Research Centre |
| JTC | Joint Technical Committee |
| RSS | Repair Scoring System |

2. Methodology

A methodology was defined to compare existing methods for assessing product reparability with that of the EN 45554. This methodology consists of the following three steps:

- Study of the EN 45554 standard by extracting its requirements and formalizing its fundamental principles.
- Identification of existing methods in the literature from papers that either propose methods similar to the one of the standard or directly use the method described in the standard to assess the reparability of mechanical products.
- Analysis of selected methods by identifying similarities and differences between them and the standard.

3. Results of the comparative study

3.1. Study of the EN 45554 standard principles

The French standard EN 45554 entitled “General methods for the assessment of the ability to repair, reuse and upgrade Energy-related Products” has been prepared by CEN/CENELEC/JTC 10 in 2020, and it refers to some international standards [1]. EN 45554 elaborates a method and criteria for assessing the ability of parts or products to be reused, repaired or upgraded. It also presents two additional methods as example. The principle of this reparability assessment method is resumed in Fig.1 below.

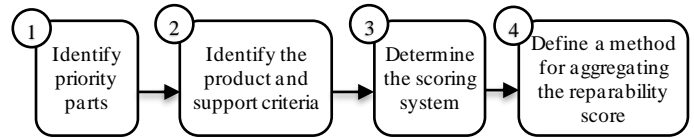


Fig. 1. Principle of the assessment method elaborated in the EN 45554 standard for ErP.

The first step of the standard principle is the identification of the priority part, because on a product, there are parts that do not need to be included in the evaluation to avoid long calculation time. It is therefore important to prioritize the parts of the product. A priority part is determined by these two points:

- The probability of its failure: parts with a high average level of failure are considered with high priority;
- Its function in the product: the parts that have or contribute to primary and secondary functions are concerned with priority.

The second step consists in identifying the product-related and support-related criteria and their applicable categories for the evaluation of each priority part. The product-related criteria are: Disassembly depth, Fasteners and connectors, Skill level, Tools, Working environment and Diagnostic support and interfaces. The support-related criteria are: Availability of spare parts, Types and availability of information, return models for repair, Data transfer and deletion and Password reset and recovery of factory settings. It is up to the user of the EN 45554 standard to define the relevant criteria to be selected for their product category.

The third step of this standard principle is the determination of the scoring system. Here, an alphanumeric value is given to each identified criterion and then replaced by a numeric value to calculate the reparability index score.

Finally, in the fourth step, an aggregation formula is used to calculate the score of reparability using a weighted system. Each criterion can be combined with a weight to form a factor that is used in this formula.

3.2. Identification of existing methods for assessing reparability.

The objective in this section was to find papers, reports or scientific research that propose a method for assessing reparability, and that have some similarities with the method described by the standard. The literature has been investigated using the Web of Science, IEEE Xplore (Institute of Electrical and Electronics) and Google Scholar databases. Over 534 articles were found with the word "repairability", and 470 articles with the word "reparability". The number of articles was then reduced by successively using keywords such as "evaluation", "determination", "assessment", "case study", "products", "score", "index". The number of articles obtained by successively adding each keyword was also sorted according to “relevance” and “number of citations”. After this systematic research, 12 papers and 2 scientific reports were found. Once these documents had been fully read, 7 articles and

2 reports were selected. They have been selected because they offer comprehensive methods for assessing reparability of EEE with example of applications. In this literature review, we did not find any papers that addressed the assessment of reparability for non-ErP. In the following, we will give short overview of the 9 selected methods. Wiens and Soules created in 2003 a repair assistance website called i-Fixit [4]. This website shows the steps to repair several EEE. For a few years now, it has been displaying the EEE reparability score obtained by the i-Fixit reparability scorecard. It therefore calculates the repair score based on a checklist of 15 criteria. The i-Fixit reparability scorecard has been applied on several EEE, such as smartphones, smartwatches, tablets, laptops and others EEE. In 2014, an Austrian standard that describes a method for assessing reparability of white and brown goods has been created. It is the ONR 192102 standard [5] which is also based on a set of criteria. It has 40 criteria for white goods (refrigerators, washing machines). It has also 53 criteria for brown goods (televisions and media players. Flipsen et al. [6] proposed a 20-criteria reparability method for electronic products based on the i-Fixit Reparability Scorecard method. They have mentioned three categories of tools which define the reparability. There is a first category of tools for measuring data, a second category for ease of disassembly and the third category is checklists that are used in the i-Fixit Reparability Scorecard method. Vanegas et al. have developed a method to assess the ease of disassembly (eDIM) in a technical JRC report in 2016 [7]. Pamminer et al. [8] developed a re-design process of a digital voice recorder in order to foster the reparability. To do so, they define a reparability analysis named Reparability Assessment Method (RAM) in collaboration with i-Fixit. This RAM is based on 6 evaluation criteria, their evaluation scales, as well as their associated weightings. Cordella et al. [9] presented a comprehensive framework for assessing the reparability and the upgradability of an ErP taking into account its environmental impact. This approach includes three levels of evaluation: qualitative based on a checklist, semi-qualitative based on parameters and quantitative based on technical and environmental criteria. In a KU Leuven Report, Bracquené et al. [10] presented a methodology for assessing reparability based on three types of criteria on information, design and service throughout the repair process. This methodology, named Assessment Matrix for ease of repair (AsMer), has 24 criteria. It has been applied on washing machines and vacuum cleaners. Another JRC technical report on the Repair Scoring System (RSS) was proposed by Cordella et al. in 2019 [11]. It is also based on 15 criteria and a weighting system. In 2020, in anticipation of the European program on ecological transition, the AGECE law [12] was voted in France and applied by virtue of article 16-I of the law n° 2020-105 against waste and for the circular economy. It aims to encourage the reuse, repair and recycling of products and industrial waste. It therefore proposes a method for assessing the reparability of several categories of EEE. An implementation of this method is available online for free in the form of an Excel grid [13]. EEE designers are required to post their reparability scores for the following products: smartphones, laptops, televisions, lawn mowers, washing machines, dishwashers, vacuum cleaners and pressure washers.

With regard to all these methods found, there are common points and divergences which are presented in the following section.

3.3. Cross-analysis of the selected methods.

In this section, a comparison between selected methods found is carried out, based on EN 45554. Among the 9 methods identified in the literature, some have similarities such the 20-criteria reparability method [6] and Reparability Assessment Method [8] that are based on the i-Fixit Reparability Scorecard [4]. After a process of inclusion and merging, such as including the ease of disassembly method [7] in the Assessment Matrix for ease of repair methodology [10], 4 quantitative reparability analysis documents have been finally selected: the i-Fixit reparability method [4], the Repair Scoring System (RSS) from European Commission [11], the Assessment Matrix for ease of repair (AsMer) [10] and the AGECE law in France [12].

The first comparison concerns the principle of the methods in terms of structure. It is a question of verifying whether the research methods follow the same principle as that of the standard presented in subsection 3.1. This comparison is summarized in Table 1.

Table 1. Comparison of the structure based on the EN 45554 principles

| EN 45554 principle | i-Fixit | AsMer | RSS | AGECE law |
|-------------------------------------|---------|-------|-----|-----------|
| Priority part definition | | x | x | x |
| Method based on criteria | x | x | x | x |
| Use of a scoring system | x | x | x | x |
| Use of a weighting system | | | x | |
| Final score obtained by aggregation | x | x | x | x |

The second point of comparison goes deeper into the principles, in terms of content. These details are illustrated in Table 2. In this point, some details are highlighted about the differences between these methods. In this table, the number of criteria, their scoring system, the weighting of the criteria as well as the weighting of the priority part and the method of calculating the aggregation of each selected method are identified and summarized.

Table 2. Comprehensive comparison

| | EN 45554 | i-Fixit | AsMer | RSS | AGECE law |
|----------------------------------|--------------|------------------|---------------|-----------------------------|-------------------|
| Number of criteria | 11 | 20 | 24 | 15 | 12 |
| Range of criteria scoring system | 0 to 1 | 1; 2 or 3 | 0; 2; 5 or 10 | 0 to 1 | 0 to 13 |
| Criteria weighting | Defined | 1 | 1 | 1 or 2 | 1 |
| Priority part weighting | - | - | - | 1 or 3 | - |
| Aggregation calculation method | Weighted sum | Sum divided by 4 | - | Sum divided by total weight | Sum divided by 10 |

The third point of comparison concerns the criteria used in each assessment methods. First, each of the selected methods has different criteria, they are listed in Appendix A. The cross-

analysis of the lists of criteria has made it possible to highlight common criteria, which can be merged, and others that are singular and specific to a certain method. This cross-analysis has resulted in a set of 39 criteria that is not yet exhaustive. This set of criteria is presented in Table 3 below.

Table 3. Summary list of the condensed criteria of the selected methods.

| N° | Criteria | EN 45554 | i-Fixit | AsMer | RSS | AGEC law |
|----|-------------------------------------------------------------------|----------|---------|-------|-----|----------|
| 1 | Disassembly depth/sequence | x | x | x | x | x |
| 2 | Disassembly time | | | x | x | |
| 3 | Tools | x | x | x | x | x |
| 4 | Fasteners | x | x | x | x | x |
| 5 | Availability of diagnostic support and interfaces | x | x | x | x | |
| 6 | Accessibility of diagnostic support and interfaces | | | x | | |
| 7 | Availability of identification support | | x | x | | |
| 8 | Accessibility of identification support | | x | x | | |
| 9 | Availability of technical support for disassembly and reassembly | | | x | | |
| 10 | Accessibility of technical support for disassembly and reassembly | | | x | | |
| 11 | Technical support for reconditioning - accessibility | | | x | | |
| 12 | Working environment | x | x | | x | |
| 13 | Skill level | x | x | | x | |
| 14 | Availability of spare parts by target groups | x | x | | x | |
| 15 | Duration time of spare parts availability | x | | x | x | x |
| 16 | Delivery time of spare parts | | | | | x |
| 17 | Interfaces of spare parts | x | | | x | |
| 18 | Price of spare parts | | x | x | | x |
| 19 | Modular design of the product | | x | x | | |
| 20 | Standardized design | | | x | | |
| 21 | Supply of spare parts - content | | | x | | |
| 22 | Type of information/documentation | x | | | | |
| 23 | Availability of information or documentation by target groups | x | | x | x | x |
| 24 | Duration time of information or documentation availability | | | | | x |
| 25 | Return options | x | | | x | |
| 26 | Software and firm ware | | | | x | |
| 27 | Ease of restoring product to working condition after repair | | | | x | |
| 28 | Availability of OEM qualified service engineers | | | | x | |
| 29 | Password reset and recovery of factory settings | | | | x | |
| 30 | Data transfer and deletion | | | | x | |

| | | | | | | |
|----|-------------------------------------------------------------------------|---|--|--|---|---|
| 31 | Warranty management | x | | | | x |
| 32 | Remote assistance | | | | | x |
| 33 | Ease of identification | | | | x | |
| 34 | Accessibility of identification | x | | | x | |
| 35 | Robustness of identification | | | | x | |
| 36 | Product designed for easy failure detection | x | | | x | |
| 37 | Product designed for ease of recovery to working condition after repair | | | | | x |
| 38 | Environmental issues at end of life | | | | x | |
| 39 | Risk of injury | | | | x | |

The last point of comparison concerns their fields of application. All these methods apply to EEE or ErP. The i-Fixit reparability score is applied to smartphones, smartwatches, tablets, laptops, solar powered LED light, and others EEE. The AsMer and RSS are applied to washing machines, vacuum cleaners and laptops. The AGECE law method is applied on smartphones, laptops, televisions, lawnmowers, washing machines, dishwashers, vacuum cleaners and high-pressure cleaners.

4. Discussion

This section consists in discussing the results obtained from the comparison between the existing methods. The literature review conducted in Subsection 3.2 highlighted a major gap in the methods for assessing reparability. It showed that there are no methods to directly assess the reparability of non-ErP, such as mechanical products. Indeed, all the methods found dealt with the reparability of the ErP or EEE. There is a need to extend the reparability to a wider range of products. Addressing this need begins with a comparative study, which is the aim of this paper. Therefore, four levels of comparison have been performed in Subsection 3.3. In the first level summarized in Table 1, the comparison between these methods based on their structure has revealed that only the RSS method uses a weighting system as recommended in EN 45554. However, the definition of priority parts is almost common to all methods, except for the i-Fixit method. All methods found are based on different criteria, use different scoring systems and aggregation calculation to obtain the final reparability score. These remarks can be confirmed in the second level of comparison which is focused on the content of the principle of each method. First, regarding the criteria, it was observed that each method has a different number of criteria. The EN 45554 standard method has 11 criteria, and scores each of them between 0 and 1. It is up to users of this standard to define their own weighting of the criteria. The i-Fixit reparability method has 20 criteria that are scored as 1, 2, or 3 while the AsMer method has 24 criteria scored as 0, 2, 5 or 10. The RSS method has 15 criteria, and the scores for each criterion range from 0 to 1. Therefore, the weights for each of its criteria are set to 1 by default, but can be doubled if the criterion is deemed more important for the product. The AGECE law method has 12 criteria that are each scored between 0 and 13. The criteria weights for the i-Fixit,

AsMer and AGECE law methods are all set to 1. Second, only RSS proposes a weighting system for priority parts. If priority parts are associated with at least 3% of failure rate, the assigned weight equals to 1. But if priority parts are associated with at least 10% of failure rate, then the assigned weight equals to 3. Finally, for all these methods, the final score is obtained by adding all the scores of the criteria and dividing it either by the sum of the weights of the criteria (in the case of the RSS method), or by a fixed value such as 4 in the case of the i-Fixit method, or by 10 in the case of the AGECE law. All these methods have differences in term of principle. But there are some similarities between EN 45554 standard and RSS on the scoring system. But also, between all of them on the criteria weighting. There are also some unclear points in the choice of the number of criteria, but also in their scoring system. According to the standard, the list of criteria can be adapted to different type of ErP. These criteria are also too generic even for ErP. Furthermore, the transition from a qualitative or semi-qualitative rating to a quantitative rating is specific to each method. This transition has not been included in this comparison study. The third level of comparison resulted in a list of 39 criteria from this study. After a cross-sectional comparison of each criterion between the methods, we found that there are some common criteria. These criteria are merged to be counted only once in the criteria list. That is the case for instance of disassembly depth, tools and fasteners criteria. There are criteria specific to a method which are also counted once, such as the criterion “Accessibility of diagnostic support and interfaces”, which is specific to the AsMer method for instance. There are also criteria with quite similar meanings that are merged and counted only once. This is the case for the “warranty problems” criterion of the i-Fixit method and the “commercial guarantee” criterion of the RSS method. They are merged into a criterion named “warranty management” which mainly concerns the number of years of commercial warranty offered. But it also takes into account some related problems linked to the respect of the warranty or not. Finally, there are criteria with sub-criteria that have been developed. For example, “Availability of spare parts” criterion has been divided into “Availability of spare parts by target groups” and “Duration of availability of spare parts” criteria for the case of EN 45554 standard. This list is made by criteria that have an impact on the whole reparability process of products. It will be used in future work as a basis of criteria for the development of a method to assess the reparability of a mechanical product. But

the usefulness of these criteria should be checked in that. In the last level of comparison, we can mainly notice that there are no reparability assessment methods for products such as bicycles or bearings. The compared methods mainly have application on products that consume energy during their use phase.

5. Conclusion

The aim of this study was to compare existing methods for assessing reparability between them and with the EN 45554 standard. This research study has highlighted an important gap in the literature regarding methods for assessing reparability. Through the literature review, we found that there are no methods that directly address the reparability of mechanical product. Existing methods are only for ErP or EEE. Following this comparative study between existing methods, we have obtained a set of 39 criteria. This set of criteria could be useful for the development of a method to assess the reparability of a mechanical product. As perspectives for this study, validation study using experts survey could be achieved in order to select the relevant criteria for the case of mechanical products. This study on reparability holds promise for facilitating the development of more sustainable PSS models that prioritize longevity and resource efficiency models by promoting standardization, improving product design, increasing compatibility.

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Appendix A. List of criteria by methods

The following lists the criteria for each of the following methods: EN 45554 standard, the i-Fixit reparability rubric, the Assessment Matrix for Ease of Repair, the Repair Scoring System, and the AGECE law method.

| N° | EN 45554 | i-Fixit reparability rubric | Assessment Matrix for Ease of Repair | Repair Scoring System | AGECE law method |
|----|-----------------------------------|--------------------------------|---------------------------------------------------|-----------------------------------------------|--------------------------------------------------------|
| 1 | Disassembly depth | Identification of the problem | Ease of identification | Disassembly depth/sequence | Documents/information |
| 2 | Fasteners and connectors | Availability of a repair guide | Accessibility of identification | Fasteners | The wording cumulatively refers to |
| 3 | Tools | Warranty issues | Robustness of identification | Tools | Technical bulletins |
| 4 | Working environment | Technical knowledge | Availability of identification support | Disassembly time | Information regarding access to professional repairers |
| 5 | Skill level | Availability of spare parts | Accessibility of identification support | Provision of diagnosis support and interfaces | Instructions for self-repair |
| 6 | Diagnostic support and interfaces | Spare parts costs | Instructions for problem identification - content | Availability and type of information | Definition of a fastener |

| | | | | | |
|----|----------------------------------------------------|---------------------------------------------|--------------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------|
| 7 | Availability of spare parts | Number of tools needed | Product designed for easy failure detection | Spare parts | Operating mode |
| 8 | Types and availability of information | Types of tools needed | Availability of failure diagnostic support | Software and firmware | Definition of spare parts distributors |
| 9 | Return models for repair | Critical components are readily accessible. | Accessibility of failure diagnostic support | Safety, skills and working environment | Commitments on the availability of spare parts and delivery times |
| 10 | Password reset and restoration of factory settings | Repair actions needed | Disassembly instructions - content | Password reset and restoration of factory settings | Delivery time |
| 11 | Data transfer and deletion | Number of screws | Product designed for ease of disassembly | Data transfer and deletion | Operating mode - calculation of the ratio for the price criterion |
| 12 | | Removability of fasteners | Required tools for disassembly | Commercial guarantee | Remote assistance |
| 13 | | Visibility of screws and other fasteners | Availability of technical support for disassembly and reassembly | Return of models | |
| 14 | | Identification of the components/parts | Accessibility of technical support for disassembly and reassembly | Availability of OEM qualified service engineers | |
| 15 | | Risk of injury | Information for spare parts | Ease of restoring product to working condition after repair | |
| 16 | | Environmental issues at end of life | Information for 3D printing of spare parts | | |
| 17 | | Fragility or robustness of components | Modular design of the product | | |
| 18 | | Internal organization of components | Standardized design | | |
| 19 | | Clarity of reparability | Supply of spare parts - content | | |
| 20 | | State after repair action | Supply of spare parts - availability | | |
| 21 | | | Supply of spare parts - cost | | |
| 22 | | | Instructions for reconditioning of product | | |
| 23 | | | Product designed for ease of restoring to working condition after repair | | |
| 24 | | | Technical support for reconditioning - accessibility | | |

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