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Investigating a repair workshop: The reuse of washing machines in Barcelona

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ABSTRACT

The reuse and repair of products are often good strategies from a holistic resource conservation perspective. Many organizations active in reuse concentrate in cities where a greater share of wasted electrical and electronic equipment is generated. The number of companies active in the reuse of these products is still limited, and information about the procedures and, more importantly, about the equipment effectively reused is not publicly available yet in many cases. This leads to imprecise knowledge about reuse in these organizations and unreliable data about the progress to a circular economy in cities and regions. The release of new standards on material efficiency represents a big step towards the harmonization of methods and indicators to monitor reuse and repair of products, but its use is challenging for existing workshops. This study examines the reuse of washing machines (WMs) at a local workshop with the objective of understanding the internal procedures for repair and reuse and defining indicators suitable to monitor these activities. The assessment at the company level shows that in 2018, approximately 77% of the WMs collected were recycled, 10% were repaired (80% of these needed multiple parts) and 2% were refurbished. At the product level, the proportion of reused components varies greatly from 4% to 14% when calculated by number on products to 60% when considering number balance. An economic analysis shows that using spare parts from wasted WMs increases the economic benefits up to 3-fold. In conclusion, the indicators proposed are useful to understand the performance of these workshops and potentially useful to quantify reuse at the city and regional scales.

1. Introduction

Technological advances in electrical and electronic equipment (EEE) have deeply influenced society since the beginning of the 1990s (Baldé et al., 2015). EEE make daily lives easier. However, there are many environmental and social impacts associated with them. For instance, the environmental impacts are generated by the extraction and processing of materials required for their manufacturing (Williams et al., 2002). Additionally, social impacts linked to occupational health and safety in informal collection and recycling (Sharma, 2015) in addition to employment quality are generally characterized by low wages, excess overtime and a lack of social security systems (Manhart, 2007). The continual increase in the amount of wasted EEE hereafter referred to as WEEE and management at their end of life represent two major concerns globally. WEEE is the fastest-growing type of waste, increasing annually from 3% to 5% (Balde et al., 2017; Guo and Yan, 2017). According to The Global E-waste Monitor 2020 report (Forti et al., 2020), the world generated 53.6 million metric tonnes of WEEE, and it is expected to increase to 74.7 million metric tonnes by 2030. In 2019, only 17% of the total WEEE generated was collected through appropriate collection schemes, while the end-of-life management of the remaining 83% was not documented (Balde et al., 2017). Eurostat estimated that from the WEEE collected in 2016, 68% was recycled, 2% prepared for reuse and the remaining 30% was incinerated or landfilled (Eurostat, 2016). Globally, almost 50% of WEEE generated by developed countries ends up in developing countries. Consequently, the management of WEEE continues to be a frequent unresolved issue in developing countries (Awasthi and Li, 2017). Some authors suggest that the continual increase in WEEE is the result of the lack of measures to counteract products with shorted life-

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times and with limitations of technological updates (Bakhiyi et al., 2018; Morris and Metternicht, 2016; Tansel, 2017).

During the past decade, the European Commission (EC) has launched a set of new directives with the aim of moving towards more sustainable products and reducing the amount of WEEE. Some of the most relevant policies include the 2009/125/EC ecodesign directive (European Commission, 2009) to improve the durability of products and make them easier to repair, reuse and recycle, the 2011/65/UE Restriction of Hazardous Substance (RoHS) Directive (European Commission, 2011) to limit the use of six hazardous materials found in EEE, and the recast of the WEEE Directive (European Parliament and The Council Of The European Union, 2012) on the End of Life (EoL) management of wastes to incentivize the collection and improve recovery and recycling of WEEE. Although these directives include several strategies towards more sustainable products, the development of specific regulations traditionally focused on the energy efficiency of products (Gabarrell Durany et al., 2017) and then the collection and recycling targets by EU members (Lee et al., 2017). The publication of the first Circular Economy Action Plan (European Commission, 2015) motivated the development of new regulations that include material efficiency implementing measures to be compulsorily implemented at the design phase of new manufacturing products and therefore enhance their repairability, remanufacturing, durability and reuse (Ardente et al., 2018). According to the latest information available from the EC website, nine out of the 31 product groups regulated for ecodesign include implementing measures related to material efficiency (European Commission, 2021). Such implementation measures vary from product group to product group. For example, the ecodesign regulation of welding equipment has requirements on the availability of spare parts, access to repair and maintenance information, delivery time of spare parts, information for dismantling, and information requirements in the instruction manuals (European Commission, 2018). The ecodesign regulation of circulators and pump devices includes only a request on information on how to install, use and maintain the product and the availability of information freely available on websites (European Commission, 2012). Including material efficiency requirements in the latest ecodesign regulations demonstrates a clear commitment to advance towards product policies that support more sustainable EEE in the EU. The effective implementation of such regulations will be reflected in an increasing amount of EEE reused and repaired and therefore a reduction in the volume of WEEE in the next years.

To investigate the impact of new ecodesign regulations in increasing the amount of reused EEE, it is necessary to obtain more comprehensive information on the processes, including the availability and typology of data along with indicators for the performance of reuse and repair workshops (Parajuly et al., 2017). In this context, the CEN/CENELEC in close collaboration with original equipment manufacturers (OEM) has published a new series of eight standards that include methods and indicators to evaluate the material efficiency aspects, such as repairability, reusability and remanufacturability of new energy-related products (European Committee for Standardization, 2020a). These standards aim to help normalize and further promote preparation for reuse within the extended producer responsibility (Grunow and Gobbi, 2009; Kunz et al., 2018; Zacho et al., 2018). However, although they represent a step forward, investigating their applicability to already existing equipment and defining additional indicators to assess reuse activities at the organization level are required. Several studies have analysed the impact of the circular economy (CE) in small and medium enterprises (SMEs) (Prieto-Sandoval et al., 2018; Thorley et al., 2019) and revised indicators of a circular economy at the microlevel (Kristensen and Mosgaard, 2020; Rincón-Moreno et al., 2021). All these studies highlighted the small number of practical studies at the micro level. However, the number of studies about social organizations active on reuse and repair is limited as well (Curran and Williams, 2010; Ongondo et al., 2013). To the best of the authors' knowledge, the existing literature focuses extensively on the discussion of CE indicators with little contribution from practice about the existing procedures at companies and how these companies need to be adapted to improve their performance. The lack of these analyses can represent a lost opportunity to prepare existing workshops for the reporting of CE indicators useful to assess reuse at greater level (i.e., cities, regions).

Following the recommendation of (Saidani et al., 2019), this study proposes the development of specific indicators tailored to a specific context with the objective of further encouraging the measurement of the performance of organizations contributing to CE strategies. As an example, this study analyses the repair and reuse of washing machines (WMs) in a local independent repair workshop in Barcelona. The study starts with a literature survey of existing studies analysing CE at the microlevel and the existing indicators to monitor reuse and repair. Then, a detailed description of the processes inspired by the methodology material flow analysis (MFA) was used to assess the performance in terms of repair, refurbishment, and reuse rates at the company level. A more detailed analysis of the internal processes allows for the calculation of some of the CEN/CENELEC material efficiency indicators at the product level. An economic analysis was further developed to understand the economic benefit of harvesting and using spare parts for repair. The study continues by discussing the use of the CE indicators proposed in workshops and how they can be used to assess reuse at a higher level to give more comprehensive information to public administrations willing to monitor progress towards CE.

2. Literature review

Although CE strategies are progressively considered to develop more sustainable products, case studies illustrating the internal procedures that products undergo in organizations to allow reuse and repair are rarely available (Curran and Williams, 2010; Ongondo et al., 2013). CE indicators, in many cases referred to as circularity indicators, fail to measure every possible CE strategy. For example, the Material Circularity Indicator (MCI) combines in one index information of the mass (virgin and recycled materials and waste) and product lifespan (Ellen MacArthur Foundation, 2015). Total restored products (TRPs) simultaneously account for products reused, refilled, refurbished, redistributed, and remanufactured at the end of life (EoL) (Pauliuk, 2018). Kristensen et al. revised 30 indicators at the micro level, most of which referred to recycling, end of life or remanufacturing (Kristensen and Mosgaard, 2020). Two out of the 30 indicators analysed focus on reuse at the product level: the potential reuse index (PRI) (Mesa et al., 2018) and the circularity calculator (CC) (IDEAL&CO Explore, 2016). At the product level, there are several CEN/CENELEC standards published in recent years relevant from a repair perspective: EN45553 to assess the ability to remanufacture products (European Committee for Standardization, 2020b), EN45554 to assess the ability for repair, reuse and upgrade score described in EN45554 (European Committee for Standardization, 2020c), and EN45556 to assess the proportion of reused components (European Committee for Standardization, 2020d). In the next section, the applicability of some of the indicators proposed will be discussed.

Regarding the analysis of WMs, Tecchio et al. developed a case study on WMs and dishwashers in collaboration with the Austrian independent repairer *Reparatur und Service Zentrum* (RUSZ) located in Vienna (Austria) (Tecchio et al., 2019, 2016). Most of the analysis was performed at the product level. However, it includes some data at the company level, which can be useful to assess the performance of the workshop. For example, RUSZ successfully repaired 5106 WMs from 2009 to 2015, which represented approximately

75% of the WMs with a declared failure. At the product level, the study includes a detailed analysis of aspects such as the durability, reusability and reparability of WMs. Regarding the reuse of WMs, the study discusses the design for disassembly, the availability of spare parts, the provision of information by the original WM manufacturer and the possibility of reprogramming the product's software and erasing error codes after repair services. In addition, it proposes the reuse index, expressed by a set of 15 different environmental impact categories commonly used in life cycle impact assessment (LCIA), as an indicator to assess the potential environmental impact of the WMs. Although the method proposed is robust and replicable, the use of LCA represents a major difficulty in performing a regular calculation of the reuse index in a small independent repair workshop due to the lack of resources and skills on the use LCA. Johnson et al. analysed the preparation for reuse of washing in Ireland (Johnson et al., 2020). The study includes a detailed flow diagram of the procedures of the company where the trials were. However, it lacks detailed information about the flows of WMs in process streams, which impedes the quantification of additional indicators related to reuse. From 327 WMs collected, only 1.5% were successfully prepared for reuse and sold in the market. This value was far from the result of the study developed at RUSZ in Austria.

3. Materials and methods

As previously discussed, this study aims to analyse the repair and reuse of WMs at the company level and at the product level. The methods used for each purpose differ from one another. At the company level, the application of the mass balance principle was a powerful tool to provide a clear definition of indicators and to quantify reused products and those reaching recycling. At the product level, the applicability of indicators included in new standards to assess reuse and repair was examined. The following section explains in further detail the methods proposed for each typology of the analysis and the potential list of indicators useful to monitor future performance. Remanufacturing, a CE strategy in which a used product (or its components) was returned to at least its original performance level, was not considered as it was generally performed by the original manufacturer (Ardente et al., 2018), which was not the case of the company selected for this study.

3.1. Analysis at the company level

At the company level, a powerful tool to obtain a more comprehensive understanding of the stocks and flows of products is material flow analysis (MFA) (Brunner and Rechberger, 2004). Based on the mass balance principle, diverse key performance indicators can be defined to assess repair, refurbishment, and reuse from a general perspective. This information is useful to obtain a general idea about the relevance of repair and reuse and to follow up the progress. This study, in line with the methodological hierarchy framework proposed by the EU H2020 project MinFuture (https://minfuture.eu), follows five main steps. The first step was to define the system boundaries along with the processes included within the system (Villalba Méndez and Talens Peiró, 2014). When the focus of the analysis was to study the circular economy indicators, it turns necessary to define concepts within the system as 'new product', 'used product', 'reused product' and 'wasted product' and identify their stocks and their flows within the system. Second, data were gathered and reported in their system context; thus, the location of data about products was clear. Third, the mass balance principle, which stands that the sum of all inputs in year j (I_j) into the system must equal all outputs in year j (O_j) plus/minus the changes in stock (Δs), as illustrated by Eq. (1) (Bringezu and Moriguchi, 2002). Mass balances allow us to ensure the consistency of the analysis.

$$I_j = O_j + \Delta s \tag{1}$$

Fourth, it was generally desirable to perform an uncertainty analysis to avoid the misinterpretation of the results and to help identify the weaknesses of the model and therefore enhance the robustness of the results and interpretations (Allesch and Rechberger, 2018). However, in some cases, the goal of the MFA does not require describing the inherent uncertainty, and sensitivity analysis and/or scenario modelling become more important elements to be taken into consideration. Fifth, based on the system definition, a list of indicators can be developed. Indicators were used to measure the performance of a system or to capture the essence of a system with numbers (Bringezu and Moriguchi, 2002; Villalba Méndez et al., 2018). When investigating the material flows of products, indicators at the process level are useful to examine the advances in reuse and recycling goals. At a greater scale, they can also support the decision-making process for the development of strategies from governments, authorities, and industries. Table 1 shows the list of proposed indicators defined for this analysis. Please note that they have been defined based on similar macrolevel indicators and data availability at the company level.

The recycling rate refers to the number of units sent undergoing recycling processes to recover materials and energy. Reuse refers *to any operation by which products or parts thereof are used again for the same purpose for which they were conceived.* Refurbish is *the functional or aesthetic maintenance or repair of an item to restore to its original, upgraded, or other predetermined form and functionality* (CEN/CENELEC, 2019). In this study, refurbishment was monitored as the refurbishment rate (Rf) and refers to the units that need aesthetic and cosmetic treatment. Repair was the *process of returning the product the ability to perform a specified function*. It might require the use of single or multiple spare parts. The repair indicators include the repair rate (Re), the single repair rate (Re1), and the multiple repair rate (Ren). Last, Sankey diagrams, which represent the inputs and the outputs while giving the magnitude of the flow (Cullen and Brazel, 2018), were the most accepted form to visualize the total material flows and the stock of the system. The reason Sankey diagrams were so useful, it was because at a glance one can gauge both the scale of a flow and how it connects with other flows.

3.2. Analysis at the product level

An initial review of data regularly collected in the workshop revealed that data about repair generally only referred to the typology and that the number of 'spare parts' and 'pieces' needed to be repaired or replaced in products, in addition to the sale price of the product once repaired. Although the repair workshop had an internal procedure to perform the disassembly of products, detailed information regarding the typology of procedures and the number of steps required to perform the repair of products was not registered. As a result, from the initial list of indicators defined by the CEN/CENELEC standards (see Table a1 of the appendix), only the 'proportion of reused components by number on product level (R_{pn}) and by number balance (R_{bn}) as defined by the EN 45,556 are possible to estimate.

Along with the reused component indicators, it was possible to evaluate the economic feasibility of the repair of products in repair workshops. In this study, the economic feasibility can be assessed by comparing the sale price of the repaired product using spare parts harvested from wasted products to the cost of new spare parts. Table 2 shows a summary of the indicators possible to quantify with already existing data collected in repair workshops.

Table 1
Suggested list of indicators to monitor reuse, repair and refurbishment at the company level.

Set of indicators defined at company level		
Indicator	**Definition**	**Formula**
Recycling rate (%)	The number of units recycled over the number of units collected.	$Rc\ (\%) = \frac{Recycled\ units}{Collected\ units}$
Reuse rate (%)	The number of units reused over the number of units collected. The number of reused units is calculated as the sum of the number of refurbished units and the number of repaired units	$Ru\ (\%) = \frac{Reused\ units}{Collected\ units}$
Refurbish rate (%)	The number of the total units refurbished over the number of units collected	$Rf\ (\%) = \frac{Refurbished\ units}{Collected\ units}$
Repair rate (%)	The number of the total units repaired over the number of units collected	$Re\ (\%) = \frac{Repaired\ units}{Collected\ units}$
Single repair rate (%)	The number of units needing a single spare part to repair over the total number of units repaired	$Re1\ (\%) = \frac{Single\ spare\ part\ to\ repair\ units}{Repaired\ units}$
Multiple repair rate (%)	The number of units needing multiple spare parts to repair over the total number of units repaired	$Ren\ (\%) = \frac{Multiple\ spare\ parts\ to\ repair\ units}{Repaired\ units}$

Table 2
List of indicators to monitor repair and reuse at the product level.

Indicator	**Definition**
Proportion of reused components by number on product level (R_{pn})	$R_{pn} = (\frac{\sum_k n_{re\_k}}{n_{tot}}) \times\ 100$ n_{re} is the number of the used components or groups of components in the assessed products n_{tot} is the total number of components in the product R_{pn} is the proportion of reused components by number of the product
Proportion of reused components by number balance (R_{bn})	$R_{bn} = (\frac{n_{bt}}{n_{units} \times n_{components}}) \times\ 100$ n_{bt} is the total number of used components or groups of components used in the defined period n_{units} is the number of units in the defined period $n_{components}$ is the total number of components per unit R_{bn} is the total proportion of reused components or groups of components by number in the defined period for the assessed products
Economic feasibility of repair using new spare parts (EF_{repair})	$EF_{repair} = PP_{rp} - \sum_i^n P_{sp\ i}$ PP_{rp} is the sale price of the repaired product using reused spare parts (€) P_{sp} is the total cost of the new spare parts (from i^{th} to n) needed to repair the product (€)

4. Results

This study analysed the reuse of washing machines at a local workshop in Barcelona (Spain). Solidança is a social Catalan-based company working in the recovery and resale of clothing and electrical and electronic equipment (EEE). This company collects these products upon request from diverse users. Then, these products were stored, tested and, if feasible, repaired within their facilities. When they meet internal quality criteria, they were sold as second-hand equipment in one of Solidança's second-hand stores in Barcelona. The EEE collected and repaired includes refrigerators, dishwashers, washing machines, dryers, microwaves, hobs, ovens, televisions, screens, monitors and small appliances. According to their annual report, Solidança managed over 1500 used EEE (weighing approximately 60 tons) in 2017. An average of 30% of all the types of EEE collected were recovered annually. Solidança has an internal record about each of the EEE collected, repaired, recycled, and sold. This study indeed aimed to perform a more precise analysis of the flows and the stock of WMs using the MFA methodology as described in Section 3 and to provide a more detailed analysis of the repair and reuse of WMs at the product level using indicators about the proportion of reused components and the feasibility of repair.

4.1. Analysis at the company level

Solidança collects used WMs from four diverse suppliers: a network of original equipment producers, households, retailers and local collection points in municipalities. WMs were first visually inspected before collection to select those with no or little aesthetic damage that were more likely to be repairable. Table a2 in the Appendix includes a short list of features considered at the on-site selection. WMs with greater damage or with one of the features listed were collected by local authorized WEEE companies to recycle. The feasible repair WMs were sent to Solidança's authorized repair workshop. At Solidança premises, the WMs were registered (including the use of labels for traceability) following internal instructions about the selection of equipment and based on operator knowledge. Amongst the information completed in the form, the registration number, the date, the collector's vehicle plate, and the origin. In the tracking file, the technician completes some descriptors of the WM: front/upper load, width (60/40 cm), load capacity (in kg), energy efficiency and motor typology (induction, universal with brushes and brushless). The form includes a list of descriptors of the physical conditions of the WM (see Table a3 in the appendix). The WMs with a mechanical time controller and small door were separated to disassemble and to harvest other parts they contain and then to be recycled. This was done because spare parts are no longer available from the OEMs, and therefore they were not reparable from a practical view. The WMs with broken drums and worn bearings were sent to disassemble and later to recycling as well, as their repair was difficult, especially when the bearings are forced into the tub of the drum. WMs with minor aesthetic damage was refurbished or repaired using spare parts from other WMs. The WMs with high damage was disassembled to harvest spare parts that will be either stocked or sent to recycling if they are damaged. Table a4 of the appendix shows the list of parts (pictures using code numbers) checked to more precisely evaluate the feasibility of repairing and refurbishing WMs. One of the reasons for not repairing some of the WMs is the cost of the time needed for reparation, as in some cases, it exceeds the economic value of the repaired WM.

All the refurbished and repaired WMs were cleaned and subjected to quality control to ensure their correct functioning. Quality control is performed to ensure the correct state of certain parts, especially the detergent drawer (3), the door and hinges (6), the readability of the list of programs in the user control board (2), feet (5), the filters (9,17) and the power cable (1). In addition to check-

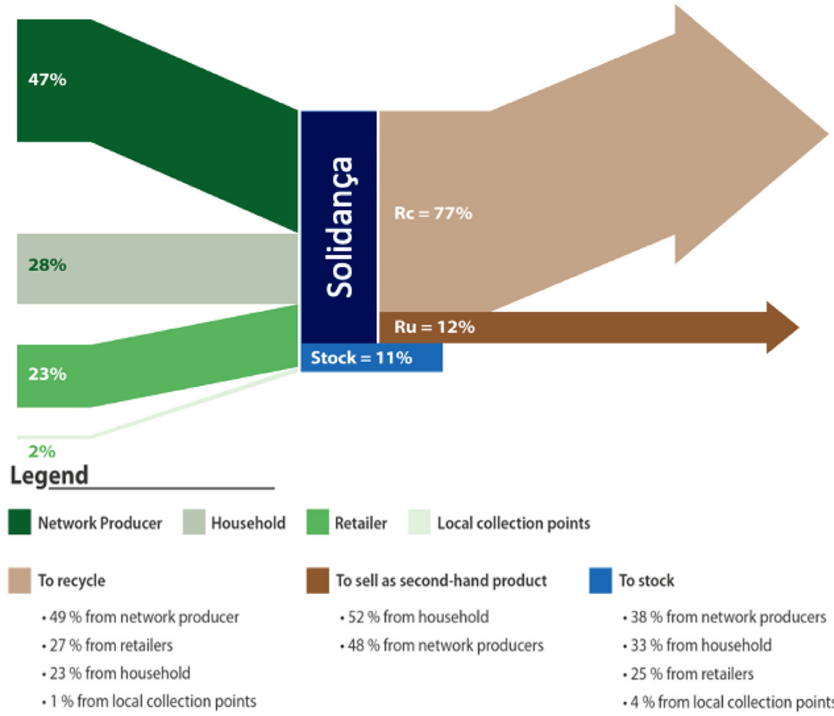

Fig. 1. Overall material flow analysis of washing machines at Solidança in 2018.

ing the state of components, WMs were tested using a portable appliance tester (i.e., Fluke 6200–2) to check the WM power and load current, the earth bonds and. The ground continuity test to ensure that the power cord resistance (voltage) of the WM should not exceed 0.2 Ohms. The dielectric resistance ensures isolation of the WMs. The resistance of a WM at 500 Volts must exceed 0.1 Ohms. All washing programs were tested to ensure the correct functioning of the WMs and checked for their cosmetic appearance. Ensuring its operation and achieving an appearance close to its original state was highly relevant for the future sale of the WM. WMs that comply with both requirements were stored and delivered to one of Solidança's second-hand stores. WMs that do not comply with the quality control and aesthetic requirements were returned to the repair workshop where spare parts are harvested and stored for future repairs. The remaining parts of the WMs were transferred to waste authorized companies where they were further recycled.

Fig. 1 shows the input of WMs from diverse sources and the output of WMs to second-hand shops and to recycling for 2018 (the latest year for which data were available). As shown, a total of 211 were collected. Nearly half of the WMs (47%) were collected from a network of WM manufacturers. Nearly 30% of WMs were collected from households, 23% from retailers and the remaining 1% from local collection points. A mass balance was performed to estimate the number of WMs to reuse, to recycle and to stock. The recycling rate (Rc) was 77%, while the reuse rate (Ru) was 12%.

Fig. 2 shows the system boundary of Solidança represented by a yellow discontinuous line. The system includes all the processes represented by dark blue rectangles: the collection, registration, testing, disassembly and harvest of parts, storage of spare parts (stock), repair and refurbishment, quality control and commercialization in one of its second-hand shops. Light blue diamond shapes represent key questions related to refurbishment and repair at Solidança. The processes outside the system are represented by yellow rectangles and include the use, the preselection performed by Solidança staff at the collection point, the collection by local authorities and the recycling of WMs. Flows denoted in dark blue refer to WM units, while discontinuous orange arrows represent the spare parts of WMs that were harvested, stocked, used for repair or sent to recycling. Once the system boundaries were defined, the input and output flows were tracked and quantified for the latest available year (2018). The quantity of WMs collected that underwent refurbishment and repair was tracked using the registration files of the WM collected and reused by Solidança. For each WM, a technician recorded manually in one tracking file information regarding the model, the brand, the mass, the Solidança label for the traceability, the repairs undergone, and the quality control dates. The tracking files were updated as the WM went through the diverse processes in the repair workshop. This information was generally kept at Solidança archives to facilitate the follow-up during the one-year warranty once the WM was sold.

Fig. 2 is also useful for identifying the most critical processes and locating potential areas to improve the implementation of circular economy strategies. For example, during the research, it was noted that some difficulties, especially in keeping the record of tracking files for some of the reused and stocked WMs. The presented research contains some limitations, as data were only available for 10 WMs out of the 21 WMs repaired. As a consequence, the results are representative of the 10 WMs whose data were available.

4.1.1. Recycling rate

The first step was the preselection of WMs to be collected by Solidança staff at the collection point. Unfortunately, not all the requests for the collection of WMs were registered, and therefore, the indicator for recycling is based only on the WMs collected and taken to Solidança facilities. The WMs collected that did not meet the requirements defined internally were sent to recycle. According to available data, the recycling rate (Rc) was 77%. Approximately half of the WMs reaching recycling were collected from the network of WM manufacturers. Retailers and households contributed equally to the share of WMs to recycle. Unfortunately, Solidança did not register the volume and typology of spare parts harvested from the WMs sent to recycling. As a result, performing a more

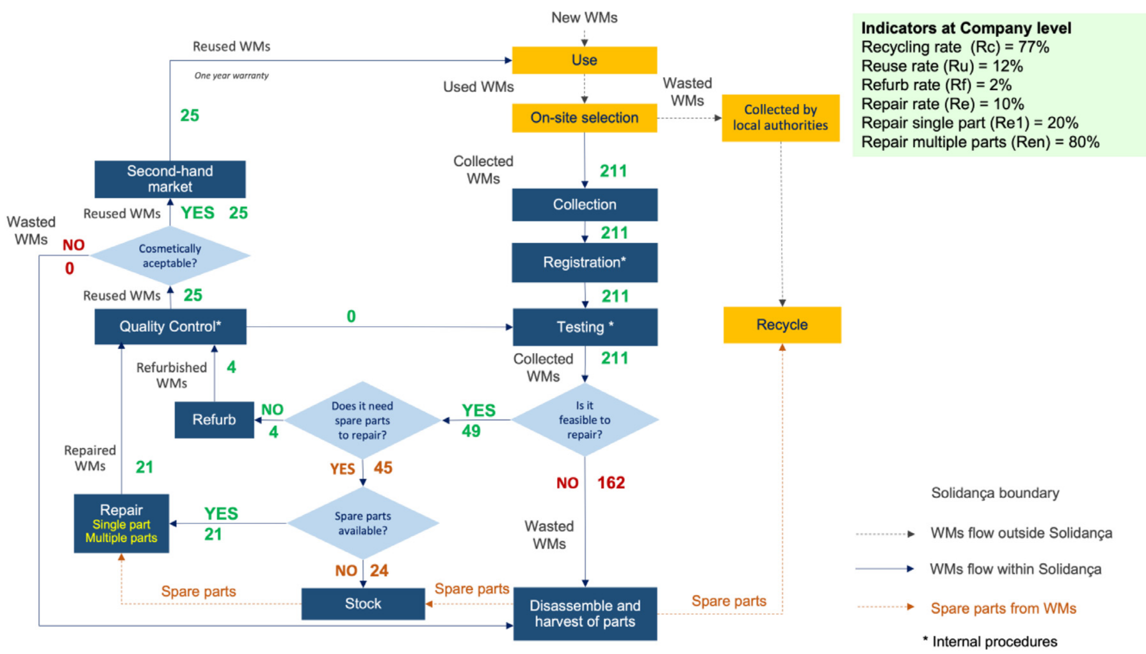

Fig. 2. Detailed flow diagram illustrating the flows and stocks of washing machines at Solidança in 2018 (all values in units of WMs).

detailed analysis of the reuse of parts from such WMs was not possible. However, further accounting for spare parts from these WM could represent an extra activity that could provide additional economic benefits by increasing repair activities.

4.1.2. Reuse rate

According to Table 1, the reuse rate was the sum of the number of WMs repaired and the number of WMs that refurbished WMs to the total number of WMs collected. In 2018, the reuse rate (Ru) of WMs was 12%. As shown in Fig. 1, the reused WMs were those collected from the network of WM manufacturers and households. There was a great discrepancy in the reuse rate at Solidança when compared to the reuse rates in Austria (75%) (Tecchio et al., 2019) and Ireland (1.5%) (Johnson et al., 2020), which emphasizes the need to develop more detailed case studies and great potential for improvement in some cases.

4.1.2.1. Refurbish rate. At Solidança, refurbishment basically consists of applying touch-up paint working in the direction of the scratch to work the enamel paint into the cut marks and letting the paint dry completely before using the appliance (Clark, 2017). The refurbishment rate (Rf) refers to the number of WMs that needed aesthetic and cosmetic treatment to return the WM to its original state. In 2018, the refurbish rate was 2%. In all cases, these WMs were rejected when they first sold, as they had one or several scratches on their external housing. Indeed, many of these WMs were never used. Solidança refurbished the front panel and/or the housing and put them back to sale in its shops.

4.1.2.2. Repair rate. According to Table 1, repair is defined as the process of returning a faulty product to a condition *where it can fulfil its intended use* (CEN/CENELEC, 2020). Single or multiple spare parts may be needed for repairing the product. In Solidança, the repair rate (Re) was 10%. Further aspects related to repair were analysed to identify those relevant to improving the repair rate. One limiting factor was the lack of detailed data from each of the WMs repaired (only available for 10 units out of the 21 units), as some of the forms were not kept on archives. Consequently, the analysis of the need for single or multiple parts was limited to the information available.

Single spare parts were needed for 20% of the WMs repaired, while 80% of the WMs needed multiple spare parts; in most cases, repair was performed by using two spare parts (see Table a6 in the appendix). The data available allowed us to examine the spare parts more frequently requested. The spare part most frequently needed was the door seal (14%), followed equally by the power cables, detergent drawer, plinth, feet, drum, pump filter, printed circuit board and drive belt (see Table a7 in the appendix). Carbon brushes and shock absorbers were replaced in a few cases as well. According to the analysis of Tecchio et al., 2016, approximately 70% of the repaired WMs had a single failure, while the remaining 30% had multiple failure modes. It also concluded that in almost 60% of the cases, the WMs required a spare part. The highest repair rates were observed for doors (including handle, hinges, lock and seal), printed circuit board, and carbon bushes (Tecchio et al., 2016). Therefore, the door seal appeared to be one of the most frequent parts to replace, followed by the printed circuit board. The removal of foreign objects was reported by Tecchio et al., 2016 as a frequent repair (8%); however, this was not registered by Solidança.

4.2. Analysis at the product level

At the product level, the two indicators possible to calculate in Solidança are the proportion of reused components and the economic feasibility of repair. To calculate the proportion of reused components, it was estimated that the total number of parts contained in a WM was 28. Table a5 of the appendix shows the list of spare parts replaced in each of the 10 WMs repaired. In approximately 60% of the WMs, the number of spare parts for repair was generally two parts, 20% only one part, and 10% three and four parts, respectively. As a result, the R_{pn} varies from 4% to 14% in 2018. The proportion of reused components by number balance (R_{bn}) was estimated to be approximately 60% based on the total number of reused spare parts (21 parts) and the total number of WMs repaired (10 units). Although this information was useful to monitor the performance of reuse, an additional investigation about the parts reused and the reasons for their replacement would be useful. Tables a6 and a7 in the supporting information show additional information about the most frequently replaced

Table 3
Economic profit of reuse when using new spare parts.

Sample	Spare parts replaced*	Spare part price (€)		Price of reused WM at Solidança's store with reused parts (€)	Economic profit when using new spare parts (€)	
		Lowest	Highest		Lowest	Highest
WM1	3,7,10,14	30	258	160	130	−98
WM2	8, 15	56	148	213**	157	65
WM3	1, 4	27	98	213**	186	115
WM4	1, 3	25	137	225	200	88
WM5	5, 13	95	338	220	125	−118
WM6	5, 7	46	113	240	194	127
WM7	4, 10, 19	28	114	213**	185	99
WM8	13	57	279	350	293	71
WM9	19	8	36	250	242	214
WM10	7, 8	56	148	300	244	152
Total economic benefit (€)					**1956**	**715**

* A full description of the parts including pictures can be found in Appendix Table a4.
** An educated guess based on sale prices within Solidança.

parts and the list of parts more frequently replaced in 2018 at Solidança.

In 2018, Solidança repaired WMs using only spare parts harvested from collected WMs. However, the repair of WMs can become a service to expand in the coming years, and therefore examining the economic feasibility of repair using only new spare parts is useful (as proposed in Table 2). To assess such an economic scenario, data were taken from a company supplying new spare parts for WMs and other electrical and electronic products (see Figure a1 of the Appendix). As illustrated, the most expensive part is the printed circuit board (PCB), which can cost almost €280. The cheapest parts to purchase are the plinth (4), pump filter (10) and drive belt (19), whose prices vary from €7 to €41. In general, the price of new spare parts varies from €6 to almost €90, except for the PCB.

Based on the cost of new spare parts, an estimate of the economic benefit at Solidança when purchasing new spare parts compared to using used parts harvested from WMs collected was done. Table 3 shows the price range for the new spare parts needed to repair the 10 WMs in 2018 and their sale price at the second-hand shop. Based on the number of spare parts replaced, an estimate of the lowest and highest profit for each case was estimated. As observed in the results, the use of reused spare parts increases the total economic benefits almost 3-fold. For two of the 10 WMs, the economic profit was negative as the cost of the new spare parts exceeded the price of the WM at the second-hand shop. For WM1, the cost was exceeded by almost €100 and was mainly due to the cost of the detergent drawer (3) and the carbon brushes (14). For WM5, the economic benefit was negative due to the cost of the PCB (13).

To obtain a more complete understanding of the cost of using new and used spare parts, the working hours of a technician to execute the repair shall be included. Unfortunately, at the time of the study, there was no registration of the time invested in repair, and it was not possible to give an estimate.

5. Discussion

The discussion is organized in two sections. The first discusses the use of the proposed indicators in existing repair workshops. The second part is a short discussion on how the indicators proposed can represent a step forward to shed light on reuse and repair activities and help emphasize the need to increase reuse and repair rates.

5.1. Definition and applicability of reuse indicators in existing repair workshops

The study of the internal procedures for repair and reuse at Solidança has helped define a list of suitable indicators at the company level and test the applicability of a set of CEN/CENELEC indicators at the product level. The results demonstrate the feasibility of defining and calculating reuse and repair indicators without a large effort whenever a detailed flow diagram of the internal processes within workshops is given. At the product level, calculating the material efficiency indicators proposed by CEN/CENELEC required a more formalized and systematized collection of data at the repair workshops, such as an exploded diagram with clear information about the dimension of parts to account for the accessibility index (I_{Acc}) proposed by EN45553 or a detailed description of the disassembly tasks to assess the indices proposed within EN45554 on the disassembly score.

The transition to a more circular economy implies joining forces from all possible existing stakeholders, including the existing independent repair workshops. Independent repair workshops play a key role in facilitating the extension of the lifetime of products at the local level. The formalization of reuse activities in these companies can be facilitated by testing the applicability of the new material efficiency standards and regulations proposed in this study. In the case of WMs, the application of the new Ecodesign regulations in March 2021 (European Commission, 2019) represents a new opportunity to facilitate repair and reuse. The current regulation establishes a minimum period of 10 years after placing the last unit of the model on the market for the availability of spare parts. It also defines a maximum delivery time and measures related to access to repair and maintenance information. However, as the lifetime of WMs varies from 8 to 15 years, the effects of such regulations will not be effectively monitored in waste flows until 2029 unless they were progressively tested in existing repair workshops. Therefore, measures to improve the collection of data and the use of material efficiency indicators in repair workshops need to be further promoted. In the case of Solidança, they could put on prospective value their repair and reuse activities and improve their capabilities. However, they could perform a communication campaign explaining their repair and reuse activities to reach more consumers and therefore divert the number of WMs to recycling despite being potentially repairable.

5.2. Accounting for reuse of EEE in cities and regions

An additional motivation of this study was to discuss the current reuse of EEE in cities and regions. To do so, the results of the case study on WMs from Solidança for 2018 was used as an example. To account for the reuse rate of WMs in Barcelona and Catalonia, data about the amount of new WMs put on the market were gathered at the Spanish Integrated Industrial Register of WEEE, in Spanish referred to as the acronym RII-AEE (Spanish Ministry of Industry Commerce and Tourism, 2020). Producers and companies commercializing any type of EEE were legally required to register in the RII-AEE database to put their devices on the Spanish market. The reported quantities referred to the legal address of the companies rather than to the city or region where the EEE were sold. Therefore, to quantify the amount of an EEE put on the market on a city or a specific region, it is necessary to do some educated guess. For instance, the quantity of WMs put on the market in Catalonia was estimated to be 614,231 units for 2018. However, this quantity does not necessarily mean that all these WMs were sold in Catalonia. A better way to quantify the new WMs put in Catalonia is to do an educated guess based on its population. Following the RII-AEE, in 2018, 1839,808 WMs were sold in Spain, which means that the WMs sold in Catalonia were 294,225 units (as Catalonia represents 16% of the total population in Spain) (Catalan Statistic Institute, 2020). Analogously, the quantity of WMs sold in the Barcelona region was estimated to be 217,727 units. During this research, five companies active in preparation for repair were identified and contacted. Three of them were not collecting WMs and therefore excluded from the study. From the other two companies, one of the other companies is a social NGO that gives low relevance to their repair activities, as their goal is to ensure the occupational insertion of jobless people, and the other company was not interested in participating in this study. As a result, the analysis of reuse at the regional level was only done with the reuse rate calculated for Solidança, which concludes that reuse is negligible. This result is in line with the 1% reuse rate published by ENVIE, the largest French Federation of reuse centres (Tecchio et al., 2016). If the reuse of EEE aims to become a real objective for governments and indicators were due to being calculated precisely, there is an urgent need to invest further in local systems such as Solidança and work on a guideline document to ensure an accurate estimate of reuse indicators in cities and regions.

6. Conclusions

This study provides a novel analysis with useful information about the internal procedures in a current repair workshop and the typology of information that needs to be further collected to account for indicators of CE. The analysis of Solidança is useful to highlight some potential improvements, such as using data collection by predetermined tracking records in electronic format in repair workshops to facilitate filling in by operators and therefore to help keep the record of the input, the output, and the stock of repaired and reused products. The need to advance towards digital data was especially stressed during the COVID-19 pandemic. Indeed, access to digital data during the past months was one of the restrictions faced during this study. Another possible improvement is the monitoring of the spare parts from products when harvested. The evaluation of the economic feasibility has demonstrated that there is a 3-fold economic benefit when reused spare parts are used for repair. Generating an electronic tracking file for spare parts could be a good approach to improve their traceability and provide more updated information and detailed descriptions about the type and number of spare parts harvested from collected products, in addition to location in the warehouse. This will allow advancement in the calculation of repair and reuse and give more confidence to the consumer to purchase second-hand products.

The importance of the reuse of WMs in Catalonia and in the Barcelona area is negligible at present when compared to the number of new WM put on the market. It is likely that a share of WMs reaching recycling is repairable, and some of them are useful to harvest spare parts to repair other WMs. Therefore, actions that help shift WMs from recycling to reuse shall be further explored. An effort to provide more disaggregated information about diverse EEE through the Spanish Integrated Industrial Register of WEEE (RII-AEE) proved useful for this study. The availability of similar data is crucial to monitor the future flows of EEE reaching recycling and reuse. Data shall become more accessible and available to account for the flows and stocks of products, especially if a circular economy continues to be a realistic goal.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.10.003.

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