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Potential reuse of small household waste electrical and electronic equipment: Methodology and case study

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ABSTRACT

This study proposes a general methodology for assessing and estimating the potential reuse of small waste electrical and electronic equipment (sWEEE), focusing on devices classified as domestic appliances. Specific tests for visual inspection, function and safety have been defined for ten different types of household appliances (vacuum cleaner, iron, microwave, toaster, sandwich maker, hand blender, juicer, boiler, heater and hair dryer). After applying the tests, reuse protocols have been defined in the form of easy-to-apply checklists for each of the ten types of appliance evaluated. This methodology could be useful for reuse enterprises, since there is a lack of specific protocols, adapted to each type of appliance, to test its potential of reuse.

After applying the methodology, electrical and electronic appliances (used or waste) can be segregated into three categories: the appliance works properly and can be classified as direct reuse (items can be used by a second consumer without prior repair operations), the appliance requires a later evaluation of its potential refurbishment and repair (restoration of products to working order, although with possible loss of quality) or the appliance needs to be finally discarded from the reuse process and goes directly to a recycling process.

Results after applying the methodology to a sample of 87.7 kg (96 units) show that 30.2% of the appliances have no potential for reuse and should be diverted for recycling, while 67.7% require a subsequent evaluation of their potential refurbishment and repair, and only 2.1% of them could be directly reused with minor cleaning operations.

This study represents a first approach to the "preparation for reuse" strategy that the European Directive related to Waste Electrical and Electronic Equipment encourages to be applied. However, more research needs to be done as an extension of this study, mainly related to the identification of the feasibility of repair or refurbishment operations.

1. Introduction

Waste electrical and electronic equipment (WEEE) is a term used to cover all items of electrical and electronic equipment (EEE) or their parts that have been discarded by their owner as waste without the intention of being reused (Step Initiative, 2014). This waste stream is characterized by its resource recovery potential and its reuse potential, being "preparation for reuse" one of the end-of-life (EoL) strategies considered as a primary option after "prevention" by WEEE Directive (Directive 2012/19/EU).

According to the definitions by Waste Framework Directive (Directive 2008/98/EC), reuse strategy contributes to reduce the quantity of waste as well as the need of raw material used in production. Reuse could be defined as using a product again for the same purpose for which it was conceived, being this achievable through a range of product life extension strategies, as repair, refurbishment and/or remanufacturing (Ijomah et al., 2004; Den Hollander and Bakker, 2012).

Many items of EEE are discarded in different conditions: with minimal use, without considering their repair or at their proper end of life (EoL). Studies in several European countries conclude that about 20–30% of discarded EEE is fit for further extended use (Agamuthu et al., 2012). So, in this context, this study is focused on proposing a first approach to the "preparation for reuse" strategy encouraged by WEEE Directive.

The WEEE Directive regulatory framework establishes minimum targets for different WEEE categories. For example, for the sWEEE category, minimum targets for recovery should be 75% and for preparation for reuse and recycling should be 55%.

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Although the management of WEEE is widely analysed in the literature from different points of views (Lee et al., 2010, 2011; Lee and Sundin, 2012; Pérez-Belis et al., 2014), greater attention is given to recycling (Cucchiella et al., 2015; Silvas et al., 2015; Tanskanen, 2013; Zhang et al., 2015; as examples) versus reuse, whose potential is discussed in works such as Cooper (2004), European Commission (2015a), O'Connell and Fitzpatrick (2008), Watson (2008) or WRAP (2011).

Few specific studies applying the reuse strategy to WEEE can be found in the literature, as Table 1 reports.

Truttmann and Rechberger (2006) was one the first study focused on analysing the resource and energy consumption involved in the reuse of WEEE (ICT and large household equipment) by comparing scenarios with and without reuse of WEEE. The conclusions of that study were that, apart from environmental aspects, other considerations such as consumer behaviour or socio-economic reasons should be incorporated into the decision-making process. Ongondo et al. (2013) analysed the operations of socio-economic enterprises involved in the reuse of ICT equipment in the UK. Kissling et al. (2013) identified specific and generic success factors and barriers in the reuse of WEEE (ICT and large household equipment) in different profit/non-profit enterprises in America, Africa and Europe. Reuse operating models were identified for these enterprises in Kissling et al. (2012).

The economic performance of reuse processes is an aspect that normally appears compared with those from recycling processes (Babbitt et al., 2011; Geyer and Blass, 2010). The environmental performance of reusing WEEE compared to other EoL strategies is an emerging aspect in the literature. Lu et al. (2014) evaluated the environmental cost and social implications of reusing mobile phones by comparing formal and informal collection and treatment sectors in China using the Life Cycle Sustainability Assessment (LCSA) methodology (UNEP, 2011). Zanghelini et al. (2014) compared the environmental performance of three alternatives for managing a discarded compressor: landfill, recycling and reuse, by applying the Life Cycle Assessment (LCA) methodology (ISO 14040-44, 2006), obtaining better results for the reuse alternative for all the impact assessment categories analysed.

However, besides the environmental and economic aspects, reuse activities also have significant social implications. Although a market for reused EEE could not be fully feasible from an economic perspective, it could be justifiable in term of its societal benefits, since the reuse activities create employment, provide a living for local communities and training for low skilled and unskilled labour (Williams et al., 2008; Streicher-Porte et al., 2009; Ijomah and Danis, 2012).

The consumers' awareness and perception of reuse of WEEE is another aspect analysed in the literature. Cruz-Sotelo et al. (2013) and Ylä-Mella et al. (2015) examined the potential reuse of mobile phones in Mexico and Spain and in Finland, respectively, by surveys. Both pointed out that current storing habits of consumers make the potential reuse of WEEE difficult. A similar conclusion was obtained by Dindarian and Gibson (2011) and Dindarian et al. (2012), who used semi-structured interviews to evaluate the consumer behaviour of consumers discarding microwave ovens. In general, the barriers for consumers to buy used products are related to consider them unattractive/old-fashioned or even "contaminated" by previous owners (Fisher et al., 2008), and to unreliable due to the lack of standards for their inspection (Wei et al., 2015).

Related to the design process of EEE, the way in which EEE is designed is crucial to assure the feasibility of its potential reuse at its EoL, being especially remarkable in the case of sWEEE (Darby and Obara, 2005). Several studies have been focused on how the design process of EEE could be addressed to facilitate the reuse activities (Rios et al., 2003; Sundin and Bras, 2005; Rifer et al., 2009; Sundin et al., 2009). A complete review of the state of the art in this field can be found in Hatcher et al. (2011) and of specific operations/times for optimizing disassembly sequences for WEEE in Goodall et al. (2014). Others studies are focused on exploring automatic end-of-life processes for disassembly specific EEE (Sundin et al., 2012).

In line with this design perspective, many products have not been designed to be durable, observing a trend of decreasing products lifespans. Nowadays, some measures are being adopted facing this situation. For example, implications of the Ecodesign Directive (Directive 2009/125/EC) for lighting and vacuum cleaners are incorporating minimum durability criteria as mandatory requirements while some labels promoting reuse and repair of products are appearing, as Miljönar label (European Commission, 2015b).

Apart from the previous mentioned aspects, the availability of a reverse logistic system for discarding EEE at its EoL, is another key aspects affecting the success of the reuse process, as Knoth et al. (2002) and Walther et al. (2010) state. A good example of the reverse logistic activities of reprocessing and repairing electrical and electronic goods by non-profit-organization could be found in Lechner and Reimann (2015), determining that in these specific cases, the reduced economic efficiency is due to the preference of ecological or social benefits rather than economical ones. Qualitative aspects of EEE reuse, such as the job creation potential and the impact on prosperity for low-income families, are also considered by O'Connell et al. (2013), supporting that if reuse of white goods were conducted by social enterprises, it would create more employment than an equivalent amount of recycling for those most vulnerable to unemployment. With this approach, they determined that a special role for the social economy in reuse policies should be considered at national levels.

On analysing the WEEE categories, from Table 1 it can be concluded that information and communication technology (ICT) and large household appliances are the WEEE categories that have been studied the most, while small WEEE (sWEEE) is one of the less studied WEEE categories (except for mobile phones (Cruz-Sotelo et al., 2013; Geyer and Blass, 2010; Lu et al., 2014; Ylä-Mella et al., 2015)). According to Annex III of WEEE Directive, sWEEE fraction includes equipment with no external dimension more than 50 cm, including household appliances, consumer equipment, luminaires, equipment reproducing sound or images, musical equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices, monitoring and control instruments, automatic dispensers, etc. Some other definition could be found at Dimitrakakis et al. (2009a, 2009b) who refer to sWEEE as the electrical and electronic equipment (EEE) that due to their small size and weight are able to be disposed of in the general household refuse. Furthermore, their different functions and variety of materials makes that most of sWEEE have several inconvenient for reuse and recycling.

Regarding the disposal habits, these have not been assimilated by consumers as in the other categories. This fact is mainly due to the lack of specific selective collection programmes for sWEEE (Dimitrakakis et al., 2009a, 2009b). However, WEEE Directive introduces a growing interest on this fraction and presents a novelty in this respect by forcing distributors, at retail shops with sales areas related to EEE of at least 400 m^2 or in their immediate proximity, to provide for the collection of sWEEE free of charge to end-users and with no obligation to buy EEE of an equivalent type. The relevance of the sWEEE fraction is due to the fact that represents one of the largest WEEE fraction by number of units (although not by weight), and is constituted by a wide variety of material among which are hazardous and valuable substances (Rotter and Janz, 2006).

Regarding international standards, only PAS 141 (2011) is specifically developed for proposing techniques for the inspection

Table 1
Review of literature applying the reuse strategy to WEEE.

Reference	Reuse aspect												Method for obtaining information			WEEE category				
	Customer awareness	Enterprises success factors and barriers	Material balance	Experience on applying PAS 141	Manage-ment practices	Functionality of discarded WEEE	Reuse vs recycling	Economic perfor-mance	Environ-mental perfor-mance	Social perfor-mance	Design (design for disassembly/ reuse, strategies, etc.)	Reverse logistic	Semi-structured interviews	Questionnaire/ survey	WEEE sample	General WEEE	ICT	Large household equipment	Mobile phone	Microwave
Knoth et al. (2002)									•		•	•			•					
Rios et al. (2003)											•				•		•			
Darby and Obara (2005)											•				•	•				
Sundin and Bras (2005)								•			•		•					•		
Truttmann and Rechberger (2006)			•				•		•						•		•	•		
Williams et al. (2008)								•	•	•		•		•			•			
Rifer et al., 2009							•				•					•				
Streicher-Porte et al. (2009)									•	•							•			
Sundin et al. (2009)											•				•			•		
Geyer and Blass (2010)							•	•							•				•	
Walther et al. (2010)							•	•				•			•		•			
Babbitt et al. (2011)					•		•	•							•		•			
Dindarian and Gibson (2011)	•					•							•							•
Dindarian et al. (2012)	•					•							•							•
Ijomah and Danis (2012)					•					•										
Kissling et al. (2012)					•								•				•	•		
Kissling et al. (2013)		•											•			•				
Sundin et al. (2012)											•		•		•		•			
Cruz-Sotelo et al. (2013)	•													•					•	
Kissling et al. (2013)		•											•				•	•		
O'Connell et al. (2013)		•						•	•	•			•					•		
Ongondo et al. (2013)		•												•			•			
Lu et al. (2014)								•	•	•					•				•	
Quarasi-Frota-Neto (2014)				•									•			•				
Zanghelini et al. (2014)							•		•						•					
Lechner and Reimann (2015)		•											•							
Ylä-Mella et al. (2015)	•						•							•	•				•	

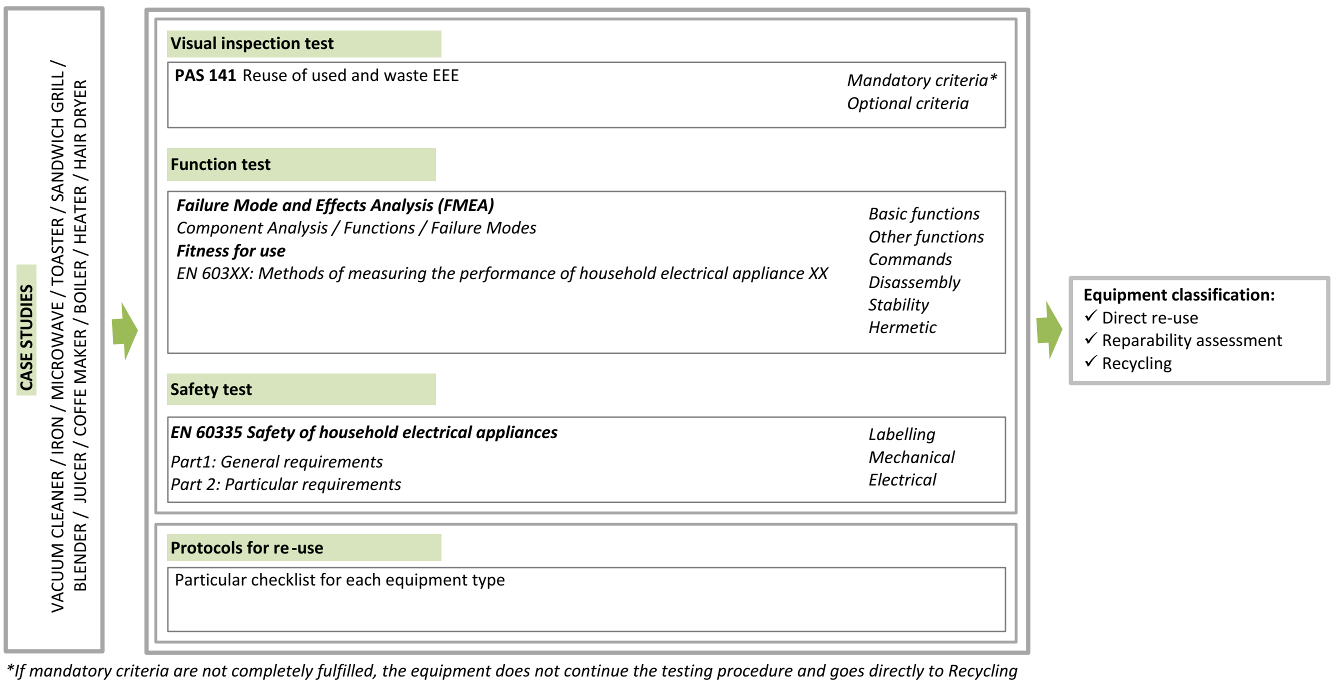

Fig. 1. Proposed methodology for preparing for reuse of sWEEE.

and preparation for the reuse of WEEE. It encourages the reuse of WEEE as promoted by WEEE Directive, by providing a framework for ensuring consumers the quality and safety of reused EEE. However, Quarasi-Frota-Neto (2014), which analyses its application in some reuse enterprises from the UK, concludes that more research needs to be done in this field considering the low market demand of sWEEE that often makes its repair, refurbishment and reselling less viable than with larger items (Darby and Obara, 2005). Other approach focused on proposing techniques for inspection during the remanufacturing processes in the automotive sector (Ridley and Ijomah, 2015), also concludes that further research need to be done in this field to facilitate the reuse activities to the corresponding industry sector.

So, taking into account this framework, this paper is focused on analysing the potential reuse of sWEEE, and specifically of household sWEEE. The aim is to propose a general methodology capable of classifying sWEEE according to its potential reuse, bearing in mind that the processes of preparing it for reuse must ensure that the equipment operates according to the requirements established for it, and there is evidence (tests) to prove it. This methodology will be applied to different household sWEEE case studies after defining specific tests (visual inspection, functionality and safety) and specific reuse protocols for each one.

2. Methodology

The proposed methodology for assessing the potential reuse of sWEEE is shown in Fig. 1 and is divided into two main parts. The first part is focused on defining tests (visual inspection, function and safety) capable of helping to decide whether the product:

- works properly and can be classified as direct reuse (items are used by a second consumer without prior repair operations),
- requires a subsequent evaluation of its potential refurbishment and repair (restoration of products to working order, although with possible loss of quality) (Pigosso et al., 2010), or
- needs to be finally discarded from the reuse process and goes directly to a recycling process.

Table 2
Criteria considered for the Visual inspection test.

Mandatory criteria	Optional criteria
• Incomplete casing • Missing elemental components • Rusted parts • Obsolete • Hygiene factors • Repairs with non-standard pieces	• WEEE logo • Missing secondary components • Crushed or damaged insulating parts • Superficial damage • Exposed electrical parts that could generate electric shocks • Unsafe electrical connection

Table 3
Example of standards consider for defining function tests.

Equipment type	Norma
Hair dryer	EN 61855
Toaster	EN 60442
Sandwich maker	EN 60442
Iron	EN 60311
Vacuum cleaner	EN 60312
Microwave	EN 60705

After defining particular tests and criteria for each equipment type, the second part, based on the experience of applying those tests, is focused on defining specific protocols for each equipment type in the form of easy-to-apply checklists for reuse centres.

This methodology could be applied by repair enterprises, defining these as centres that carry out all reuse activities, from collection, inspection and repair to sale of the reused items. Most of these organizations are social insertion enterprises focused on creating jobs for people at risks of social exclusion. They receive training and are involved in every stage of the reused process (collection, inspection, repair and sale).

2.1. Visual inspection test

According to Sundin and Bras (2005), the first step in a generic reuse process is inspection. So, the initial step in the proposed

Table 4
Example of standards considered to define safety tests.

Equipment type	Standard		Common tests
Hair dryer	EN 60335-1	EN 60335-2-23	• Classification
Toaster		EN 60335-2-9	• Labelling and instructions
Sandwich maker		EN 60335-2-9	• Protection against access to live parts
Iron		EN 60335-2-3	• Heating
Hand blender		EN 60335-2-14	• Voltage, power and current validation
Juicer		EN 60335-2-14	• Electric isolation
Vacuum cleaner		EN 60335-2-2	• Circuit breaker
Microwave		EN 60335-2-25	• Cable
Boiler		EN 60335-2-15	• Etc.
Heater		EN 60335-2-40	

Fig. 2. Example of photos from the selective collection of sWEEE (containers, transportation and characterization).

Table 5
Amounts (kg and units) selected from the pilot selective collection campaign in the subcategories of household sWEEE to apply the proposed methodology.

Subcategory	Equipment type	Units	Weight
Cleaning equipment	Vacuum cleaner	7	32.57
	Iron	30	44.15
Food equipment	Microwave	5	55.69
	Toaster	14	18.65
	Sandwich maker	6	13.69
	Hand blender	17	14.68
	Juicer	8	8.89
Hot water	Boiler	4	2.88
	Heater	6	9.16
Personal care	Hair dryer	17	8.92

methodology is based on a visual inspection to check whether the appliance and its main components are in good working order, in terms of its visual appearance and overall condition. The general criteria proposed for the visual inspection test are detailed in Table 2. These tests were defined based on the requirements of PAS 141 (2011), protocols defined by WRAP (2015) for large electrical and electronic equipment, and in cooperation with a local company authorized for the management of WEEE. Criteria are divided into two categories: mandatory and optional. Mandatory criteria are defined based on the minimal threshold criteria for reuse. Appliances that do not meet those compulsory criteria are discarded and go directly into the flow of products for recycling. Appliances that do satisfy these mandatory criteria go on to a second stage to evaluate their functionality and safety in order to determine if the sWEEE can potentially be prepared for reuse, either because they work properly or because they need to be evaluated against their potential reparability.

2.2. Function test

The function test is based on evaluating and verifying that the equipment operates according to the functions and requirements established for it, and there is evidence (tests) to prove it. To do this, initially it is proposed that a failure mode and effects analysis (FMEA) should be conducted in order to determine the characteristic components of each equipment type, their functions and ways in which they can fail. The results of the FMEA, as well as the specified function tests defined by different standards (Table 3), make it possible to define the functions to be checked for each equipment type.

2.3. Safety test

The safety test is based on checking whether the equipment is safe for consumers by evaluating basic aspects related to electrical, mechanical and thermal risks. General tests common to all household electrical and electronic equipment are defined by standard EN-60335-1, while specific tests for each equipment type can be found in the set of standards EN 60335-2, as Table 4 reports.

2.4. Reuse protocols

After defining and applying the tests described below, and according to Rreuse (2015), Sundin and Bras (2005) or WRAP (2015), for an efficient identification of equipment with potential for reuse, rapid accurate inspection procedures need to be designed to sort them out from the sWEEE stream at an early stage.

Recently, the British Waste & Resources Action Programme (WRAP, 2015) has developed and published a set of experience-based industry protocols, highlighting the tests and minimum procedures to be performed for a number of categories of WEEE, such

Table 6
Criteria considered for the visual inspection test for each equipment type.

Visual inspection test criteria	Code	Hand blender	Juicer	Microwave	Vacuum cleaner	Hair dryer	Sandwich maker	Toaster	Iron	Boiler	Heater	Mandatory criteria
WEEE logo	V1	x	x	x	x	x	x	x	x	x	x	
Incomplete casing	V2	x	x	x	x	x	x	x	x	x	x	x
Missing elemental components	V3	x	x	x	x	x	x	x	x	x	x	x
Rusted parts	V4	x	x	x	x	x	x	x	x	x	x	x
Obsolete	V5	x	x	x	x	x	x	x	x	x	x	x
Hygiene factors	V6	x	x	x	x	x	x	x	x	x	x	x
Non-standard parts	V7	x	x	x	x	x	x	x	x	x	x	x
Missing secondary components	V8	x	x	x	x	x	x	x	x	x	x	
Crushed or damaged parts	V9	x	x	x	x	x	x	x	x	x	x	
Superficial damage	V10	x	x	x	x	x	x	x	x	x	x	
Exposed electrical parts that could generate electric shocks	V11	x	x	x	x	x	x	x	x	x	x	
Unsafe electrical connection	V12	x	x	x	x	x	x	x	x	x	x	

Table 7
Criteria considered for the function test for each equipment type.

Function test criteria		Code	Hand blender	Juicer	Microwave	Vacuum cleaner	Hair dryer	Sandwich maker	Toaster	Iron	Boiler	Heater
Basic functions	The device is turned on when the ON button is activated	F.B1	x	x	x	x	x		x	x	x	x
	Blades rotate properly	F.B2	x									
	The reamer rotates by pressing the top cover	F.B3		x								
	Beverages and/or foods are heated adequately	F.B4			x				x		x	
	Adequate dust extraction occurs on a flat surface	F.B5				x						
	Adequate dust extraction occurs on carpet	F.B6				x						
	Check whether the dust is being collected in the internal container	F.B7				x						
	Responds correctly at each temperature level	F.B8					x					
	The appliance heats properly	F.B9						x		x		x
	The temperature of the soleplate is uniform across the surface	F.B10						x		x		
	The automatic stop function works properly	F.B11							x			
	The slices of bread are raised properly by the toaster	F.B12							x			
Secondary functions	The noise is below 65 dBA	F.S1	x	x		x	x					x
	The device responds to each power option	F.S2	x		x	x	x		x			x
	Rotational motion occurs in both directions	F.S3		x								
	The device responds to the defrosting option	F.S4			x				x			
	The glass tray is properly engaged and rotates when Start has been pressed	F.S5			x							
	Indicator light comes on when the appliance is in use	F.S6			x							x
	The duration of the warming cycles matches the time selected by the user	F.S7			x							
	The cord can be extended without difficulty	F.S8				x						
	The cord rewinds without difficulty	F.S9				x						
	The automatic shutdown function works properly	F.S10						x				
	The non-stick plates fit perfectly	F.S11						x				
	A slice of bread remains warm on the support	F.S12							x			
	The temperature levels of the device work properly	F.S13							x	x		x
	The steam spray function works properly	F.S14								x		
	The spray nozzle works properly	F.S15								x		
	Cold air function works properly	F.S16					x					x
	The cover opens automatically on demand	F.S17									x	
Buttons and commands	The ON/OFF button works properly	F.C1	x	x		x			x		x	x
	The power selection button works properly	F.C2	x		x	x	x		x			x
	The time selection button works properly	F.C3			x							
	The temperature selection button works properly	F.C4					x	x		x		x
	The fan selection button works properly	F.C5					x					
	The defrost button works properly	F.C6							x			
	The cancel button works properly	F.C7							x			
	The steam spray button works properly	F.C8								x		
	The spray nozzle button works properly	F.C9								x		
	The additional command to open the cover works correctly	F.C10									x	
Dismantling and cleaning	The device can be easily dismantled into its main parts	F.D1	x	x	x	x			x		x	x
	The dust bag is accessible	F.D2				x						

(continued on next page)

Table 7 (*continued*)

Function test criteria		Code	Hand blender	Juicer	Microwave	Vacuum cleaner	Hair dryer	Sandwich maker	Toaster	Iron	Boiler	Heater
	The different heads of the device are attached and fit together properly	F.D3					x					
	Minimum opening of 90° for easy cleaning of the plates	F.D4						x				
	No obstruction when filling with water	F.D5								x		
	The filter can be removed	F.D6									x	
	Crumbs are collected in the bottom of the toaster in the slide-out tray	F.D7							x			
Stability	It is stable in the vertical position	F.ST1	x	x	x	x		x	x	x	x	x
	Good adhesion to the surface	F.ST2			x			x	x	x	x	x
	The wheels work properly	F.ST3				x						
	The jar fits into the base	F.ST4									x	
	Vibration is not excessive	F.ST5										x
	Fitted with a ring for hanging the device	F.ST6					x					
Impenetrability	Tight-fitting closure	F.H1		x	x	x		x			x	
	Liquids cannot get inside the appliance	F.H2	x						x			
	It has no blockages, the squeezed liquid flows normally	F.H3		x								
	Hoses are undamaged	F.H4				x						
	Hoses fit the appliance correctly	F.H5				x						
	Head of the device and hose fit together correctly	F.H6				x						
	No leakages	F.H7					x			x	x	
	Blades cannot be reached by hands	F.H8										x

Table 8
Criteria considered for the safety test for each equipment type.

Safety test criteria		Code	Hand blender	Juicer	Microwave	Vacuum cleaner	Hair dryer	Sandwich maker	Toaster	Iron	Boiler	Heater
Labelling	Electric shock protection class on label matches corresponding standard	S.L1	x	x	x	x	x	x	x	x	x	x
	Rated power input in watts	S.L2	x	x		x			x	x	x	x
	Specific information about the appliance detailed in the standard	S.L3			x		x	x				
	Marking of nominal frequency in megahertz of ISM band	S.L4			x							
	Marking indicating its volumetric capacity	S.L5									x	
Mechanical risks	Active parts must be inaccessible when open/closed	S.M1	x	x	x	x	x	x	x	x	x	x
	The cable must be smooth and free of any sharp edges	S.M2	x	x		x	x	x	x	x	x	x
	The cable must withstand a force of 10 N when swung through 180°	S.M3	x	x			x			x		
	The cable must withstand a force of 10 N when stretched	S.M4			x	x		x	x		x	x
	The cable must withstand torsion and flexion movements	S.M5					x		x	x		
	The cable must not be able to go inside the product	S.M6							x	x		
	Power cords should not be longer than 75 cm	S.M7									x	
	The devices should be stable	S.M8	x	x	x	x		x		x	x	x
	Devices must incorporate a continuous action button	S.M9	x									
	The continuous action button should prevent accidental operation	S.M10	x									
	The blades must not touch a flat surface when they rotate	S.M11	x									
	Food/liquids must not come into contact with live parts	S.M12	x	x								
	Devices must have a stop-operation button	S.M13									x	
	The cover must not fall off while water is poured in	S.M14									x	
	Devices must be fitted with a thermostat	S.M15										x
Electrical risks	The voltage on the name plate must match the measured voltage	S.E1	x	x	x	x	x	x	x	x	x	x
	The power on the name plate must match the measured power	S.E2	x	x	x	x	x	x	x	x	x	x
	The theoretical current must match the measured current	S.E3	x	x	x	x	x	x	x	x	x	x
	Electrical insulation test	S.E4	x	x	x	x	x	x	x	x	x	x
	Heating test based on the requirements of the respective standards	S.E5	x	x	x	x	x	x	x	x	x	x
	The lamp of the circuit breaker turns off correctly	S.E6						x	x	x	x	x
	The current must fall to 0 when the circuit breaker has been activated	S.E7						x	x	x	x	x

as fridge-freezers, televisions, washing machines and mobile phones. However, none of them is specific enough to assess the potential for reuse of household sWEEE.

Based on those protocols, a set of specific reuse protocols were defined for the household sWEEE detailed in Fig. 1, in the form of checklists that are easy for reuse centres to apply. The content of the protocol needs to consider aspects related to: general characteristics of the equipment (date, category, subcategory, equipment type, code identification, etc.), identification of the person in charge of testing the equipment, result (pass/fail) for each particular criterion of the visual inspection, function and safety tests, and final classification of the equipment according to the following three criteria:

- At least one mandatory criterion of visual inspection test fails. The equipment needs to be finally discarded from the reuse process and goes directly to a recycling process.
- At least one criterion of the visual inspection, function or safety test fails. The equipment requires a subsequent evaluation of its potential refurbishment and repair.
- All criteria of the visual inspection, function and safety test are passed. The equipment works properly and can be classified as direct reuse with minor cosmetic cleaning.

3. Case study

The proposed methodology described in Section 2 has been applied to different types of equipment included in the category household sWEEE. The sample comes from a selective collection campaign of household sWEEE held in Castellon de la Plana (Spain) from March to June 2015.

The campaign was carried out in collaboration with a social insertion enterprise which is authorized for the management of WEEE. The selective collection points were located in different educational centres located across the town. Containers of 240-l of capacity were provided by the insertion enterprise, being after that identified with the image of the campaign. These containers where located in the halls of the educational centres (indoor). Simultaneously, parents of children from these centres were informed about the collection campaign through a two-page leaflet, explaining both the objectives of the campaign and the type of small household WEEE that could be disposed (sWEEE with no external dimension more than 50 cm, e.g. irons, toasters, sandwich makers, hand blenders, etc.). Once a week, containers were checked by the research group and the sample was carefully collected and transported to the laboratory where its classification took place, as Fig. 2 shows.

A total of 823.14 kg were collected from 14 temporary selective collection points (15 days per point). 53% (by weight) belong to the category small household equipment, 28% to the category small IT and 17% to the category screens, according to the classification of WEEE proposed by Baldé et al. (2014). The remaining 3% was composed of improper waste belonging to other waste streams. As this study is focused on analysing the potential reuse of the subcategory household sWEEE, Table 5 shows the equipment type (amounts and units) collected in this subcategory.

In accordance with the proposed methodology, visual inspection, function and safety tests have been defined specifically for each equipment type reported in Table 5.

The criteria considered for the visual inspection test are reported in Table 6. All the criteria are common for each

Equipment category:	**Date of reception:**
Equipment subcategory:	**Identification CODE:**
Equipment type:	**Test person:**

VISUAL INSPECTION TEST	PASS	FAIL
WEEE logo		
Incomplete casing*		*
Missing elemental components*		*
Rusted parts*		*
Out of order*		*
Hygiene factors *		*
Non-standardized pieces*		*
Missing secondary components		
Crushed or damaged parts		
Superficial damages		
Exposed electrical parts that could generated electric shocks		
Unsafed electrical connection		

**If mandatory criteria are not completely fulfilled, the equipment does not continue the testing procedure for function and safety and goes directly to recycling*

SAFETY TEST		PASS	FAIL
Labelling	Mark referred to the protection against electric shock –(own standard)		
	Rated power input in watts		
Mechanical risks	Active parts must be inaccessible in open/closed		
	The cord must be smooth and without sharp edges steps		
	The cord must withstand a force of 10 N when stretched		
	The devices should be stable		
Electrical risks	The VOLTAGE on the name plate must be checked with measured voltage		
	The POWER on the name plate must be checked with the measured power		
	The theoretical CURRENT must be checked with the measured current		
	Electrical insulation test		
	Test of heating based on the respective standards requirements		

FUNCTION TEST		PASS	FAIL
Basic functions	The device is turned on when the button ON is activated.		
	A suitable dust extraction occurs on flat surface		
	A suitable dust extraction occurs on carpet		
	Check if dust it is being accumulated in internal container		
Secondary functions	The noise is below of 65 dBA		
	The devices responds to every power option		
	The cord should be extent without difficulty		
	The cord should roll out without difficulty		
Buttons and commands	The ON/OFF button works properly.		
	The button of selection of power works properly		
Dismantling and cleaning	The device could easily dismantled into its main parts		
	The bag of dust is accessible		
Stability	It is stable in the vertical position		
	The wheels work properly		
Impenetrability	Hoses fitted correctly to the appliance		
	Hoses should be undamaged		
	Hoses fitted correctly to the appliance.		
	Head of the device and hose are fitted correctly		

RESULTS	
AT LEAST ONE MANDATORY CRITERIA OF VISUAL INSPECTION TEST FAILS *The equipment needs to be finally discarded from the reuse process and goes directly to a recycling process*	
AT LEAST ONE CRITERIA OF THE VISUAL INSPECTION, FUNCTION OR SAFETY TEST FAILS *The equipment requires a posterior evaluation of its potential refurbishment and repair*	
ALL CRITERIA OF THE VISUAL INSPECTION, FUNCTION AND SAFETY TEST PASS *The equipment works properly and can be classified as direct reuse with minor cosmetic cleaning*	

Fig. 3. Common structure of protocols for reuse (example for vacuum cleaner).

equipment type. However, four criteria (incomplete casing, missing elemental components, rusted parts and obsolescence) are considered mandatory criteria according to both Walther et al. (2010) and the experience of the WEEE company. Equipment that does not fulfil these criteria, defined as threshold criteria, has no potential for reuse and, therefore, does not require any additional testing.

The criteria considered for the function test are reported in Table 7 for each equipment type. For this test, the criteria are specific for each equipment type and the way each criterion is applied to each type is also specific. The procedure applied, as well as the criteria for deciding whether it meets or does not meet the requirements, are defined for each equipment type from standards such as those reported in Table 3. Besides the direct observation of the operation of the equipment by the researcher, the main tools/lab equipment used for conducting the function test were a sonometer to measure the level of noise and a wooden ramp to analyse the stability of the equipment on a common table.

The procedure followed to define the safety tests is similar to those described for the function test. Table 8 shows the criteria for each equipment type according to standards such as those reported in Table 3. The main tools/lab equipment used to conduct the safety tests were a megohmmeter to analyse the electrical insulation of the equipment, a multimeter to measure active electrical parameters, a thermometer to identify overheating and a weight for performing resistance tests on the cable.

Fig. 4. Results obtained for each criteria and for each equipment type after conducting the visual inspection test.

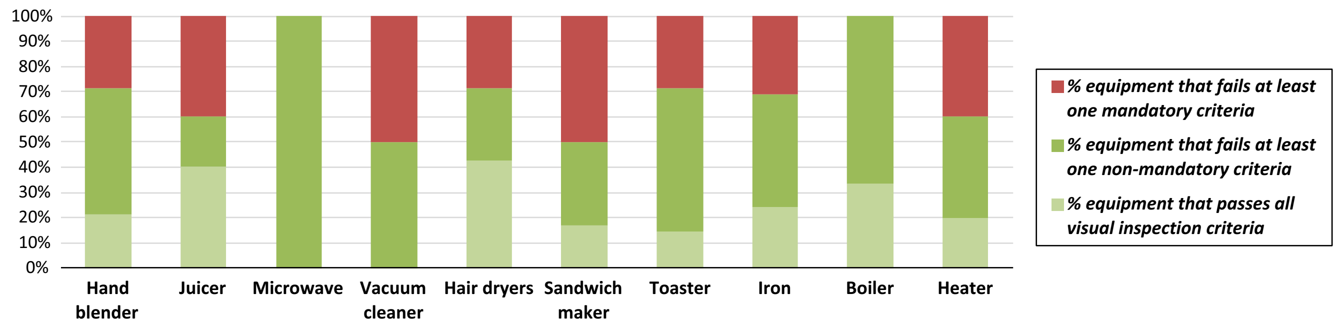

Fig. 5. Aggregated results for each equipment type after conducting the visual inspection test.

Once the tests for evaluating the potential reuse of each appliance have been defined and after applying them, protocols that are useful for reuse centres are defined in the form of easy-to-apply checklists. These protocols are specific for each equipment type, although a common structure has been defined, as shown in Fig. 3.

4. Results

The collected sample selected for each equipment type (Table 5) was analysed by applying the methodology described in Fig. 1. Figs. 4–9 show the results obtained after conducting the visual inspection, function and safety tests. The code used for each criterion has been previously described in Tables 6–8, for visual inspection, function and safety tests, respectively.

Fig. 3 shows the percentage of the appliances analysed that pass or fail each criterion defined for the visual inspection test in Table 6. This makes it possible to identify the most common visual faults for each equipment type. Regarding the mandatory criteria (V2-V7), it is observed that the criteria of having incomplete casing (V2) and missing elemental components (V3) are the main criteria that make the appliances included in equipment types such as hand blenders, vacuums or sandwich makers fail the visual inspection test, which means that they will be diverted directly to recycling with no potential for reuse. The obsolescence of the product (V5), understood to mean that the product should not be processed for reuse since there are no longer any commercially available parts (or suitable alternatives) on the market, is only observed in the case of hair dryers, toasters and irons. V4 is only failed in the iron and toaster equipment type, although in a very low percentage. All the microwaves and boilers evaluated passed all the mandatory criteria.

In reference to the non-mandatory criteria (V1, V8-V12), V8 (missing secondary components) along with V10 (crushed or damaged parts) are the most common failures for most of the equipment types analysed. Regarding the first criterion about the WEEE identification (V1), it can be observed that V1 fails in approximately 50% of the hand blenders, juicers, vacuum cleaners, hair dryers or sandwich makers. This implies that most of them were manufactured before 2005, the year in which displaying the WEEE logo became mandatory. The criterion related to the exposure of electrical parts that could generate electric shocks (V11) only failed in microwaves, while the unsafe electrical connection criterion (V12) was not failed in any of the appliances analysed.

If results are aggregated by equipment type, Fig. 5 shows that, on average, 31.3% of the appliances evaluated fail at least one mandatory criterion and are discarded for the following tests, 47.9% fail one or more non-mandatory criteria and only 20.8% pass all the criteria described in Table 6, both mandatory and non-mandatory.

Fig. 6 shows the percentage of appliances analysed that pass or fail each of the criteria specifically defined for the function test in Table 7 for each subcategory. This allows the most common function failures to be identified for each equipment type. It can be observed that function criteria related to basic functions (F.BX) fail in most of the equipment types, mainly F.B1. Criteria related to buttons and commands (F.CX) and dismantling and cleaning (F.DX) are normally satisfied by most of the appliances, although this rate is lower in microwaves (F.C2 and F.C3) and heaters (F.D1), respectively. Stability criteria (F.STX) are successfully satisfied by all the equipment analysed. Finally, most of the appliances pass the impenetrability criteria (F.HX), except for a low percentage of irons (F.H7) and boilers (F.H1).

If results are aggregated by equipment type, Fig. 7 shows that, on average, 91% of the appliances evaluated fail at least one function criteria, which means that a later analysis of their reparability is needed after being classified as potentially reusable. Only 9% pass all the criteria described in Table 6 for each equipment type.

Fig. 8 shows the percentage of appliances analysed that pass or fail each criterion specifically defined for the safety test for each subcategory in Table 8. It also helps to identify the most common safety failures for each equipment type. It can be observed that safety criteria related to labelling are normally satisfied by most of the appliances, except for sandwich makers, hair dryers, microwaves and hand blenders (S.L1, S.L2, S.L3, S.L4), mainly due to the fact that the name plate was unreadable or missing. In reference to the mechanical test (S.MX), the highest percentages of failure are observed in criterion S.M2 (cable), mainly for hair dryers and sandwich makers. Results from criteria related to the electrical test (S.EX) show the highest percentage of failure and unverifiable compared to the remaining tests, except for boilers. Juicers, microwaves, hair dryers, toasters and heaters are the equipment types with the highest percentage of failure, mainly in criteria S.E2, S.E3 and S.E4.

If results are aggregated by equipment type, Fig. 9 shows that, on average, 77.6% of the appliances evaluated fail at least one safety criterion, which means that a subsequent analysis of their reparability is needed after being classified as potentially reusable. Only 22.4% pass all the criteria described in Table 7 for each equipment type.

As has been stated before, after filling in the particular protocol designed for each equipment type in accordance with the format report in Fig. 4, appliances can be classified into three groups: direct reuse, requires repair assessment or recycling. Fig. 10 shows the aggregated results for the visual, function and safety tests, for each appliance. So, it can be concluded that 30.2% (ranging from 50% to 100%, depending on the equipment type) of the sample

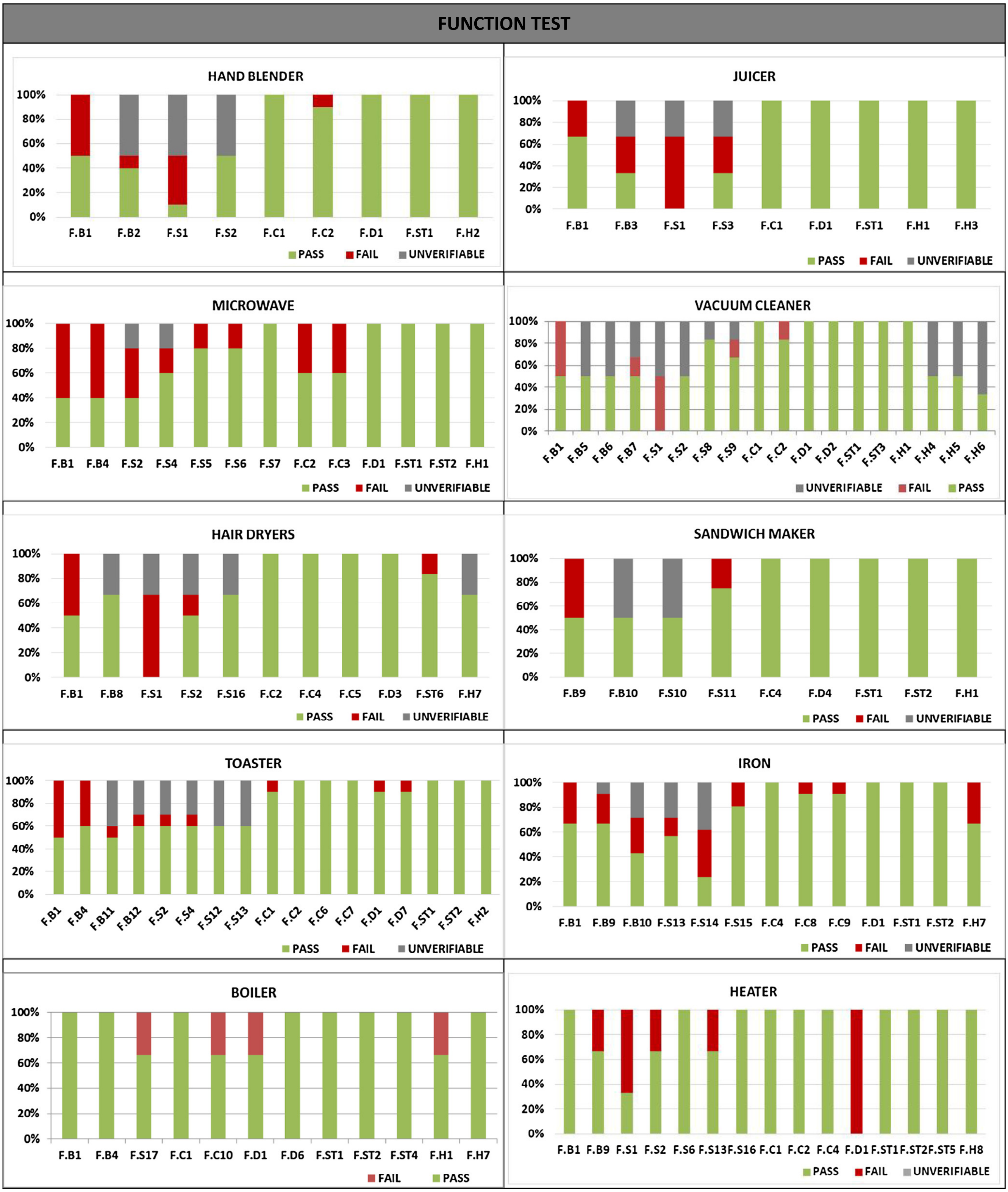

Fig. 6. Results obtained after conducting the function test for each equipment type.

gathered from the selective collection of household sWEEE has to be diverted to recycling due to the fact that at least one mandatory criterion of the visual inspection test has not been satisfied. An average of 67.7% (ranging from 50% to 100% depending on the equipment type) of the sample thus collected requires a posterior evaluation of its potential refurbishment and repair because they have failed at least one criterion (non-mandatory). Only 2.11% of the total sample (20% of the microwaves collected and 7% of the toasters collected) can be classified as direct reuse after minor cosmetic cleaning, because after passing all the criteria for the visual inspection, function and safety tests, there is evidence that they work properly.

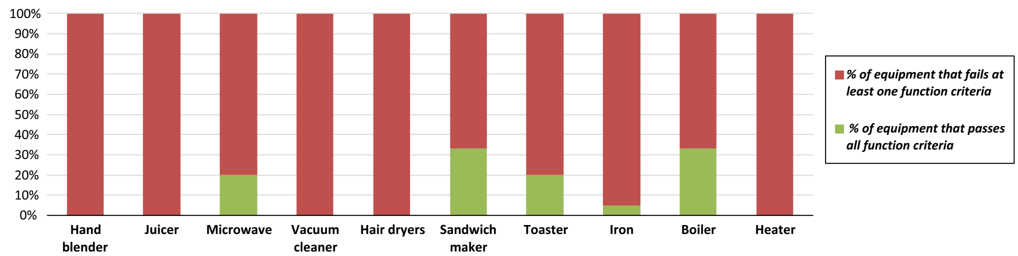

Fig. 7. Aggregated results for each equipment type after conducting the function test.

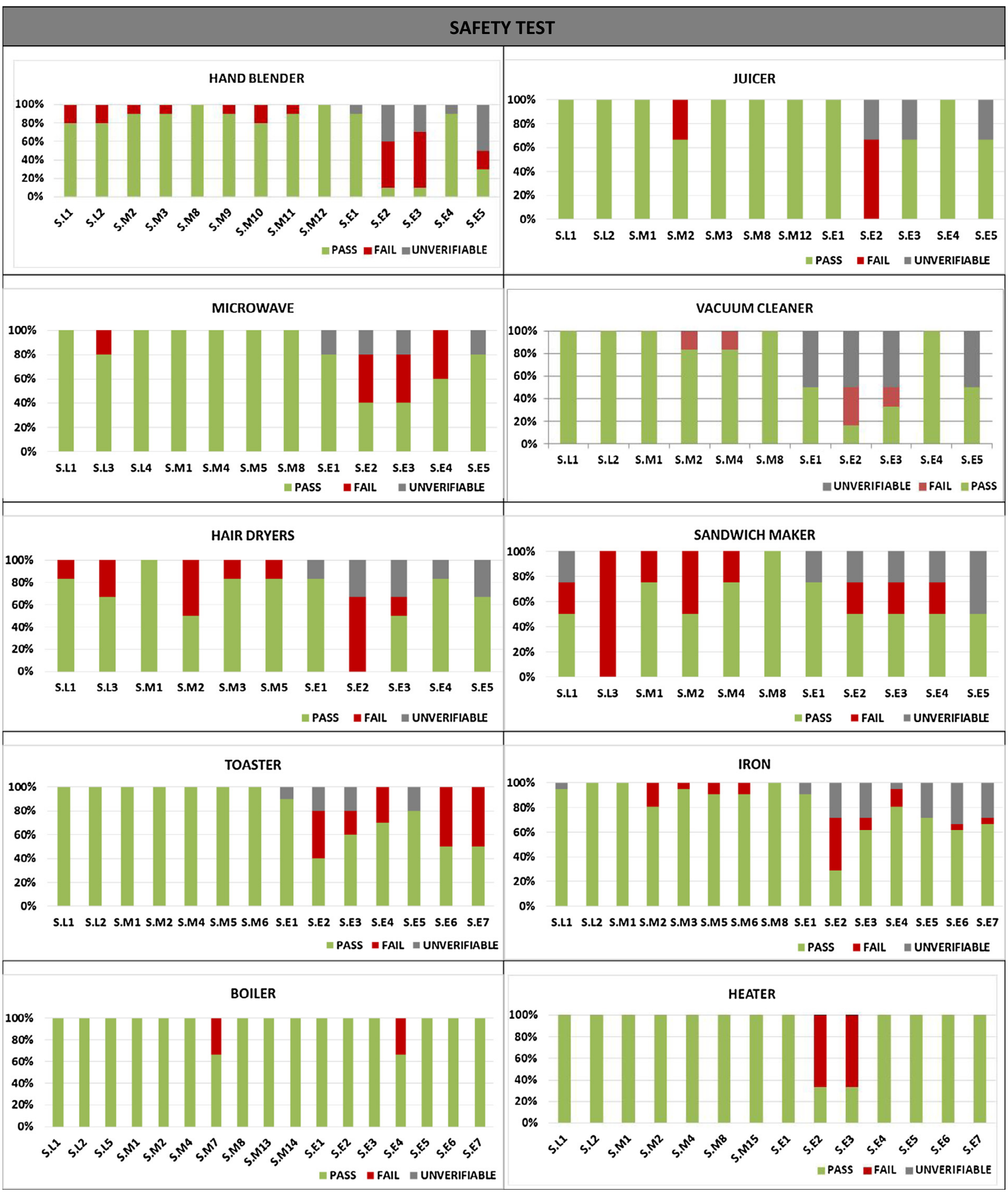

Fig. 8. Results obtained after conducting the safety test for each equipment type.

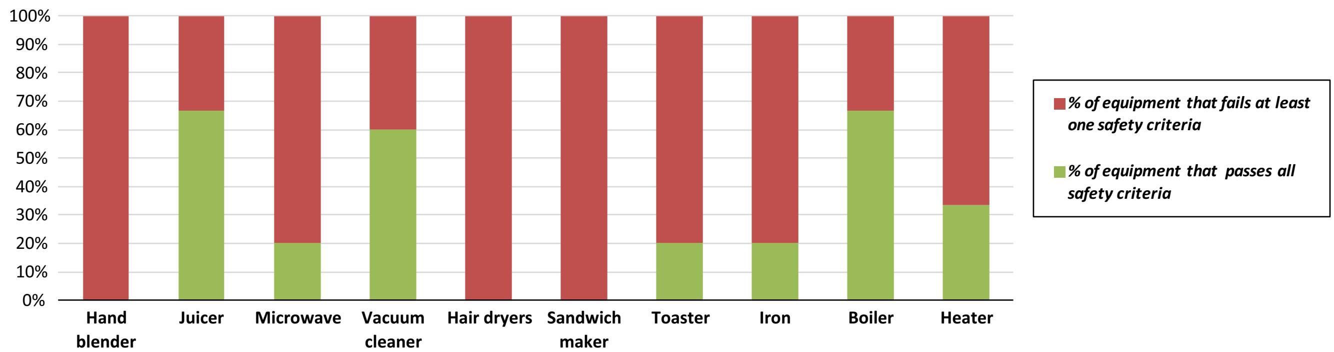

Fig. 9. Aggregated results for each equipment type after conducting the safety test.

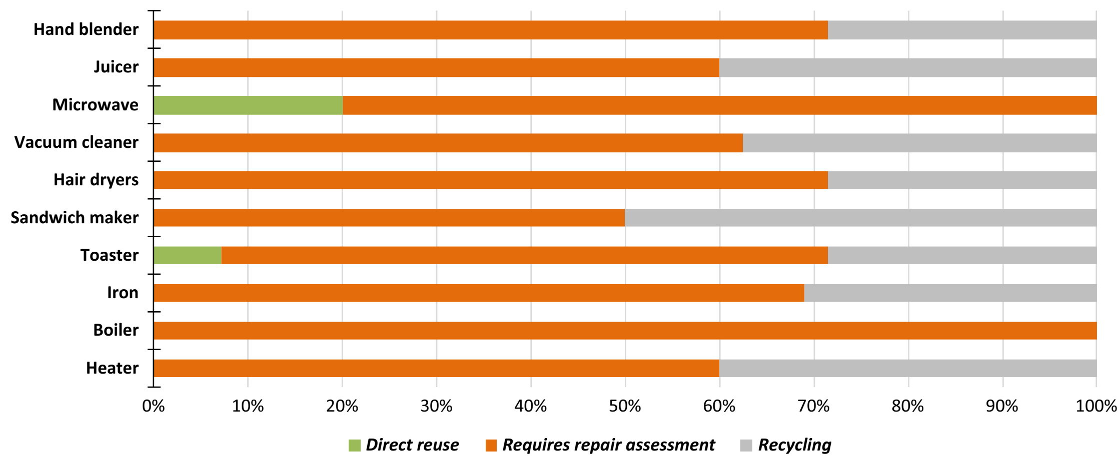

Fig. 10. Results obtained per equipment type of the analysed sample.

4. Conclusions

This study has proposed a general methodology for assessing and estimating the potential reuse of sWEEE and, specifically, household sWEEE. This methodology could be useful for reuse enterprises, since there is a lack of specific protocols, adapted to each type of appliance, to test its potential of reuse.

Particular tests for visual inspection, function and safety have been defined for ten different household sWEEE (vacuum cleaner, iron, microwave, toaster, sandwich maker, hand blender, juicer, boiler, heater and hair dryer). After the experience of applying the tests, reuse protocols have been defined in the form of easy-to-apply checklists for each of the ten equipment types evaluated. In this way, at the end of the process each appliance can be classified into one of the following three groups:

- Recycling, with no need to carry out the process of analysing its potential reuse, in a second stage.
- Repair assessment is required.
- Direct reuse with minor cosmetic cleaning.

After assessing a sample of 87.7 kg (96 units) from a campaign for the selective collection of household sWEEE, 30.2%, 67.7% and 2.1% of the appliances analysed belong to the groups of recycling, potential reuse and direct reuse, respectively.

This means that a potential reuse of 70% can be obtained from the household sWEEE stream. This study has allowed us to identify the main characteristic failures for each equipment type. In general, missing elemental components (mandatory criteria), missing secondary components and superficial damage are common faults from a visual perspective, failure of a basic or secondary function from a functional perspective, and failures in the cable or electrical risks from a safety perspective.

Six criteria have been defined as mandatory criteria in the visual inspection test. However, more research needs to be conducted in order to define which repair or refurbish operations are feasible from different points of views, i.e. technical, economic and environmental. This study will continue in this line with the aim of identifying mandatory criteria in the function and safety tests that allow a classification into three final groups: direct reuse, feasible repair or refurbishment and recycling. This further classification would help to determine which components fail often or which components could be recovered from a non reusable product in order to integrate them into other products.

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