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Design and Development of a Pilot Plant for WEEE-Computers Reusing

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Abstract: This paper is focus on one of the main problems at the end of useful life of electrical and electronic equipment (eee). waste of eee (weee) are growing at a rate three times faster than the rest of the solid waste and it is expected to be more than 12 million tonnes by 2020 in the ue, according to european commission. as a consequence of this important issue, an environmental project was developed called ecoraee by a consortium of two companies and university of vigo. this project aims to solve the weee problem from different points of view: technical, environmental and also economic, and it was funded by life European program (life env/es/574 11).

According to circular economy, actions to contribute to 'closing the loop' of product lifecycles must be done in order to sustainability. in the case of eee there are two options: just recycling or reuse before recycling. increase useful life of eee, especially computers, is best way to reduce the problematic of weee. department of mechanical engineering at university of vigo leads, within ecoraee project, the demonstration of a reuse process for computers could be done under a perspective of enlarge useful life to different application. in fact, an operation process is defined to prepare any computer to reuse in three specific applications:

- recover material to create a building air-conditioning control and lighting system (demo 1)
- create a cluster of computers for grid processing (demo 2)
- create perimeter security devices for intranets (demo 3)

Under these conditions of computers reuse, a demonstrative pilot plant was designed and finally built at university of vigo, including the implementation of flow of operation to reuse. a pilot plant was operative from march to september 2014 and they were processed about 4-5 computers per day. taking into account that there was a first stage of set-up of the plant, the result during the second stage (full operative stage) of computer processing for each demo show a tax pcs reuse of about a 21% and a 25% in the case of demo 1 and demo 3, respectively, in which full computers reused, and about of a 100% of hdd and a 50% of motherboards in the case of components reused.

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Ecoraee pilot plant shows that reuse of computer is technically possible in order to enlarge useful life of computers, or components, to a second use. pilot plant was also electrically and energetically monitored and the results of computers processing were used by other research groups involved in ecoraee project to make an environmental analysis of weee reuse.

Key words: Waste of Electrical and Electronic Equipment', WEEE, pilot plant, reuse, UE LIFE program

1. Introduction

One of the major environmental problems and waste treatment to which our society will have to face today is the proper processing of WEEE (Waste Electrical and Electronic Equipment). This fact is also growing in the coming years. This paper is focus on one of the main problems at the end of useful life of those Electrical and Electronic Equipment (EEE), which waste is growing at a rate three times faster than the rest of the solid waste and it is expected to be more than 12 million tonnes by 2020 in the UE, according to European Commission [1]. Nowadays, more than 85% of WEEE are improperly collected and processed, although there are European regulations (such as Directive 2002/96/ EC [2]) which aim is to promote the collection, recycling and recovery of any electrical appliance. Add to this, the environmental problems of WEEE are particularly important due to the presence of various types of materials between its components: glass to plastic; metals, in particular heavy metals and contaminants (lead, mercury, cadmium, selenium and arsenic).

ecoRaee project (named 'Demonstration of a re-use process of WEEE addressed to propose regulatory policies in accordance to EU law' [3]), funded under the European Life (LIFE 11 ENV/ES/574 [4]) was developed with the ambition to solve the WEEE problem in a viable way, not only technical and environmental, but also economic. According to circular economy [4], actions to contribute to 'closing the loop' of product lifecycles must be done in order to sustainability. In the case of EEE there are two options: just recycling or reuse before recycling. Increase useful life of EEE, especially computers, is best way to reduce the problematic of WEEE. Base on this, University of Vigo is driving and leader this project and, in particular, Department of Mechanical Engineering is charged, within ecoRaee project, with the design and development of a pilot plant for WEEE-computers reusing, in which an economical and technical WEEE-reuse process is demonstrated, under a perspective of enlarge EEE useful life for different applications. In fact, an operation process [6] is defined to prepare any computer to reuse in three specific applications (three demonstrative processes or demos):

- recover material to create a building air-conditioning control and lighting system (Demo 1)
- recover material to create a cluster of computers for a grid-processing unit (Demo 2, in which only two

components of the full computer (HDD and motherboard) have been reused)
- recover material to create a perimeter security device for intranets (Demo 3)

To address this project, it has been taken into account previous papers related to the processing of WEEE. Most of them refer to recycling, not to reusing, but to compare benefits and advantages of reusing versus recycling; those studies are presented, considering that recycling is, up to nowadays, the most common processing of this kind of WEEE devices.

Manage of electronic waste has been studied by several authors in numerous as Queiruga et al., 2012 [7] which refers to the WEEE management in Spain, compared with proposals from other countries, such as for example, Switzerland, that was pioneer in the management of WEEE. Wäger et al. 2011 [8] have compared recycling of WEEE in Switzerland, in current scenario (year 2009) versus recycling status years ago (year 2004), and they assessed that the environmental impact of WEEE collection in that country has been reduced by 14% between these 5 years, thanks to a better management due to favourable political initiatives undertaken. This fact makes Switzerland as an example for many other countries in terms of management WEEE regulations, especially in the case of emerging countries, such as Sri Lanka (Mallawarachchi and Karunasena, 2012 [9]), Brazil (Oliveira et al. 2012 [10]), India (Wath et al., 2010 [11]) and China (Wei and Liu, 2012 [12]).

In other Spain neighbouring countries, such as Portugal, proper WEEE management actions are also carrying out (Nice et al., 2014 [13]), such as the implementation of policies of manufacturers responsibility in the management electric-electronic equipment (EPR-Extended Producer Responsibility).

Other many authors have proposed a review of the existing legislation on WEEE recycling/reuse, such as Gottberg et al., 2006 [14] which reviews the specific European regulations in the lighting sector, also proposing the responsibility of the manufacturer (EPR) as the way to the correct processing of this kind of WEEE. Kiddee et al., 2013 [15] review the state of the art about WEEE processing, focus on the definition of toxic substances in these products ('e-waste') and the recycling, by a safe method, of dangerous substances. Laurent et al., 2013 [16] review studies on management of solid waste recycling, not only WEEE, but including the mention of WEEE management based on Swiss regulations as reference. In relation to regulations, Xevgenos et al. (2015) [17] present a large collection of studies about waste policy and legislation in Europe, Japan and USA, exemplified in 19 municipalities of those regions. They compare methodologies of waste recycling, by an economical way, including recycling of WEEE devices and strategies of ‘Zero Waste’. They also present that there are high recycling rates in municipality with small population.

A previous characterization is an important necessary step needed for properly WEEE management, due to the great diversity of existing electric-electronic equipment. Authors like Menad et al, 2013 [18] propose a new characterization of them based on several parameters such as the existence of plastic or metallic materials

(especially in relation to hazardous substances) and average size and shape of the parts. These authors analyse two samples of products to determine, in order to facilitate future strategies for management, the percentage of plastic/metallic/non-metallic components in each of them and sizes of those parts. Another study on the characterization of WEEE, in this case about small devices (coffee machines, PCs, irons or dryers) is carried out by Chancerel and Rotter. 2009 [19], that they study the composition (percentage of plastics, metals, etc.), including hazardous materials, in those small EEE. In the same way, other authors focused on another specific electric-electronic equipment, such as Pérez-Belis et al., 2013 [20] focus on the toy industry in Spain; Rubin et al., 2014 [21] who analyse strategies for recycling components, especially, copper on printed circuits (PCB); and Williams et al., 2008 [22] which focuses its study on personal computers (PCs). In relation to PCs components re-valorisation, several authors analyse methodologies to recycling PCB by chemical methods (Yildirir et al., 2015 [23]) or the evolution of PCB hazardous substances (Chan and Valix, 2014 [24]). Anonakou and Achilias (2012) [25] study recent advances in valorisation of polycarbonate during PC recycling, and also Williams (2010) [26], analyse this item focus on PCB and using pyrolysis as recycling methodology.

Several authors have developed tools to analyse environmental impact of WEEE processing, such as Achillas et al. (2010) [27], focus on optimizing by proposed mathematical models applied to a real case, different methods of transport equipment (trucks, trains, boats, etc.) to improve the distribution of WEEE processing centers and logistics involved. Also, Casamayor and Su (2013) [28] develop a tool that analyses the environmental impact of reuse electronic components, in particular, applied to lights. Ordoñez and Rahe (2013) [29] propose that WEEE environmental impact could be reduce from the design phase if that design is focused on make them easier and efficiently manageable and taken into account their end-of-life. Finally, other authors such as Manfredi and Goralczyk (2013) [30], propose to propose recycling strategies in the European Union based on indicators defined by a life-cycle assessment.

In relation to computer equipment reuse, which is the aim of this paper, there are not many current works. We can remark Truttmann and Rechberger (2006) [31], in which authors show that the reuse of computer components extends the life-of-use of the product, but on the other hand, remain on the market obsolete which are less efficient than the newer ones. However, studies show that the reuse of all types of EEE implies a 12% saving energy, especially PCs which are the 5.4%. These paper shows that define appropriate policies to PC reuse, that is the aim of present work, is useful to solve WEEE problems. In fact, this paper shows a demonstration of an actual pilot plant to reuse PCs that is current working at University of Vigo.

2. Methodology

According to circular economy, actions to contribute to ‘closing the loop’ of product lifecycles must be done in order to sustainability. In the case of EEE there are two options: just recycling or reuse before recycling. Increase useful life of EEE, especially computers, is best way to reduce the problematic of WEEE. Department of Mechanical Engineering at University of Vigo leads, within ecoRaee project, the demonstration of a reuse process for computers could be done under a perspective of enlarge useful life to different application. In fact, the definition of a technically optimal layout to industrial implementation of the process of WEEE reuse / recycle is carried out in this project. For the definition of the handwork needed to PCs’ process operations, previously defined [6]. Process layout is made of taking into account the optimization, not only in cost, but also in time, and therefore reducing environmental impact during operations. Several conceptual proposals were done: first, ‘operations’ in the centre of the process with hand-workers around (Fig 1, top); and secondly, ‘men’ (workers) in the centre, to optimize space and streamline operating time, with operations around (Fig. 1, bottom).

Based on this second concept design, pilot plan is constituted by a series of work-sites where the necessary operations to WEEE reuse are performed, in concrete, for PCs and also peripherals/components (HDD, keyboard & mouse, etc.). In this pilot plant, reuse equips and device are prepared to use in the three demonstration applications defined (demo1, demo2 and demo3). The design of the WEEE-reuse pilot-plant includes also the structure support and all necessary equipment for the complete obsolete PCs processing. Next figure (Fig. 2) shows CAD3D model of the pilot plant site on Mechanical Engineering Laboratory at University of Vigo, and it is formed by:

- Support structure
- Electrical installation to feed electricity in different work-site
- Computer equipment and tools to PCs reuse
- Storage site to obsolete PCs equipment, components and peripherals, and the final reuse product

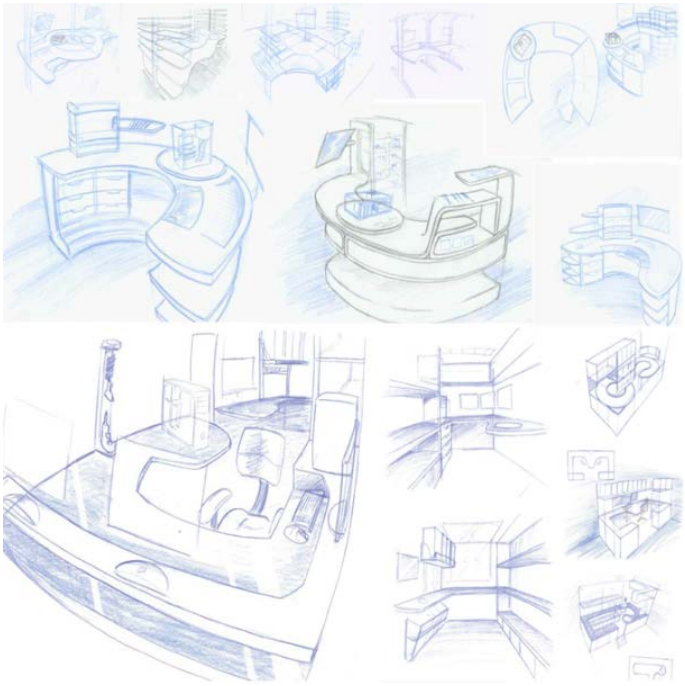

Fig. 1. Concepts defined for WEEE processing layout: initial (top) and end (bottom)

Fig. 2. Pilot plant CAD model

3. Results and Discussion

This section is focus on pilot plan construction and the development performance test during WEEE-PC's reuse process. This pilot plan is still operative, located at the Laboratory of Mechanical Engineering in the University of Vigo. For each of the three demos, as shown in the following table (Table 1), necessary operations to prepare WEEE for reuse were defined. In addition, Fig. 3 shows reuse flow-operation (Demo 1) inside the layout of the pilot plant. In order to improve productivity and the number of computers that can be treated, two flow lines were defined: first, a rapid flow, for those PCs that due to the good-state of its components need only a basic processing; and another, slow flow, for PCs that need as much repair operations and/or be dismantling due to its worst-state. Different images of reuse operation are showed below (Fig. 4).

Table 1. List of reuse operations in each demo (demo1, demo2, demo3)

DEMO 1	*DEMO 2*	*DEMO 3*
TR 1 - 2: Filtering equipment	TRI 1 - 2: Filtering equipment	TR 1 - 2: Filtering equipment
TR 10: Treatment components.	TRI 10.1: Recovery cabling.	TR 10: Recovering components.
TR 3.1: Classification of basic equipment.	TRI 10.2: Classification of wiring.	TR 3.1: Classification of basic equipment.
TR 3.2: Test POST.	TRI 3.1: Basic Criminalization of equipment.	TR 3.2: Test POST.
TR 3.3: Comprehensive Classification of teams.	TRI 3.2: Test POST.	TR 3.3: Comprehensive Classification of teams.
TR 3.4: Manually checking components.	TRI 3.3: Comprehensive Classification of teams.	TR 3.4: Manually checking components.
TR 3.5: Determination of the target configuration.	TRI 8.1: Erasing disc.	TR 3.5: Determination of the target configuration.
TR 8.1: Erasing disc.	TRI 7.1: Removing equipment.	TR 8.1: Erasing disc.
TR 7.1: Cleaning and sanitization.	TRI 7.2: Classification of components.	TR 7.1: Cleaning and sanitization.
TR 7.2: Assembly of equipment.	TRI 5: Diagnosis.	TR 7.2: Assembly of equipment.
TR 7.3: Installing software.		TR 7.3: Setting client.
TR 7.4: Checking communications.		TR 7.4: Checking and final testing.
TR 7.5: Performance testing.		TR 5: Diagnosis.
TR 5: Diagnosis.		

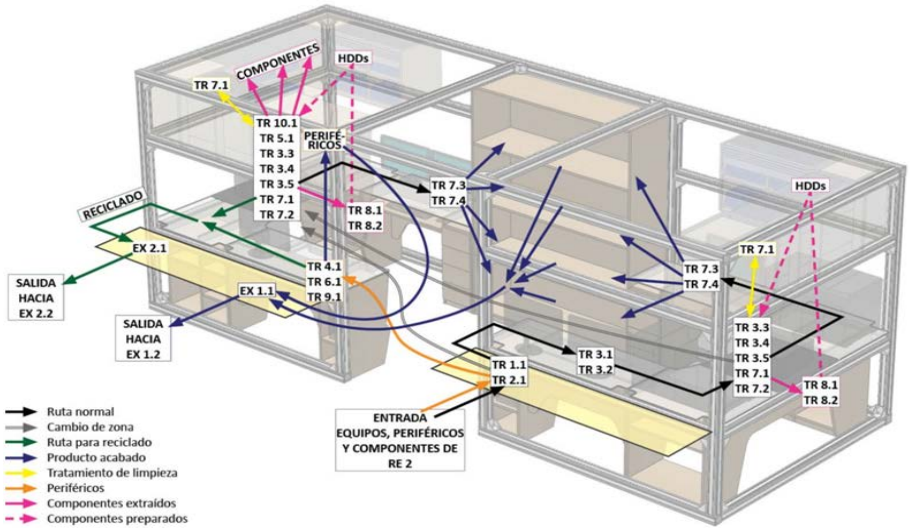

Fig. 3. Demo1 flow-operation

Fig. 4. T3.2: Turn-on and first check (left), T3.4: checking hardware (center) and T8.1: HDD-format (right)

Fig. 5 TR7.1: Internal cleaning of hardware (left), classification of cables (center) and components (right)

Fig. 6. TR7.2: Assembly of motherboards (left) and HDD (center), and TR7.3: SO installation (right)

Since pilot plant star-up, in March 2014, this installation has been continuously processed PCs up to September 2014. All reuse PCs were used to the three Demos and the leftover PCs were donated to different academic centers (Primary and Secondary Schools), NGO or any other association. During May 2014, the installation was tuned and optimized, with the first PC processed. Next table (Table 2) shows the results obtained during the set-up of the plant.

Table 2. Initial PCs processed in the pilot plant at University of Vigo (May 2014)

DEMO	*Dates*	*Number of days*	*Computers processed*	*Aceptable to reuse*
Demo 1	12/05/2014 - 19/05/2014	6 days	33 units (358,9 kg)	7 units (75,2 kg)
Demo 2	26/05/2014 - 03/06/2014	7 days	23 units (299,4 kg)	12 components* (14.8 kg)
Demo 3	19/05/2014 - 23/05/2014	5 days	42 units (417,4 kg)	7 units (80,0 kg)

* Taking into account that in Demo 2 just only motherborads and HDD are reused

Pilot plant was operative from March to September 2014 and they were processed about 4-5 computers per day. After the first month, during the set-up of the plant, the result obtained for the PC-WEEE reuse process at full operative stage, were the following for each demo (Table 3).

Table 3. PCs processed in the pilot plant at University of Vigo (full operative stage)

DEMO	*Dates*	*Number of days*	*Computers processed*	*Aceptable to reuse*
Demo 1	05/06/2014 - 14/07/2014	20 days	90 units (934,9 kg)	7 units (75,2 kg)
Demo 2	18/08/2014 - 15/09/2014	20 days	100 units (400 kg)	75 components* (300 kg)
Demo 3	15/07/2014 - 12/08/2014	20 days	68 units (697,6 kg)	16 units (177,6 kg)

* Taking into account that in Demo 2 just only motherborads and HDD are reused

4. Conclusions

WEEE management represents one of the main problems of waste management and its treatment must be increased the next year. Nowadays, more than a 4% of total EU waste is coming from EEE and it is increased three times faster than other solid waste. ecoRaee project, funded under the European Union Life+ program (Life11 ENV/ES/574) and it is focus on providing technical, economic and environmental benefits to WEEE reuse, making a demonstration of its viability. University of Vigo (Mechanical Engineering Research Group) takes part in this project by defining and designing an optimized WEEE recycling/reuse pilot plant, which allows providing a reusable PC equipment or PC component to a new valid use. This pilot plan was built in the Mechanical Engineering Laboratory and it was operative from March 2014. It provides reuse PCs for three different demonstrative processes.

The results show a tax of mass reuse of about a 21% and a 25% in the case of Demo 1 and Demo 3, respectively, in which full computers are reused, and about of a 100% of HDD and a 50% of motherboards in the case of components are reused.

ecoRaee pilot plant developed shows that reuse of computer is technically possible in order to enlarge useful life of computers, or components, to a second use. Pilot plant was also electrically and energetically monitored and the results of computers processing were used by other research groups involved in ecoRaee project to make an environmental analysis of WEEE reuse.

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