E-Waste management framework and the importance of producer responsibility and proactive hackerspaces

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Abstract— **WEEE (waste electrical and electronic equipment) is estimated to be one of the fastest-growing waste stream worldwide and in the EU. Due to its content of dangerous substances, it is considered and regulated as hazardous waste. At the same time WEEE is a potential source for recuperation of valuable materials, such as precious metals. This paper presents the current European regulatory framework concerning WEEE management. As part of the assessment, fulfilment of the producer responsibility principle in the context of WEEE management is analysed as an example of implementation of the principle in practice. Furthermore, the paper explores selected consumer-initiated initiatives. The goal of the work is to frame and examine the topic WEEE under an EU lens and to highlight selected responses to the issue of WEEE increase, and more generally to explore current responses for sustainable management of this material stream.**

The EU WEEE Directive sets targets to reduce generation of WEEE and to enhance proper collection, re-use and recycling of this material stream, encouraging producer responsibility as key principle. In response to the directive, the European Recycling Platform, that is the first ever pan-European producer compliance scheme, was established for providing an alternative concept to national monopolistic schemes. While in Europe top-down approaches based on regulatory frameworks have become common in WEEE management, consumer-initiated bottom-up initiatives to address WEEE are comparatively rare, but can become vital elements to lower occurrence of such waste streams. Community-based hackerspaces are one example of proactive response towards reduction of avoidable e-waste and should therefore be fostered.

Keywords- WEEE; e-waste, waste electrical and electronic equipments; producer responsibility; European Recycling Platform; recycling; hackerspaces; makerspaces

I. INTRODUCTION

The use of electrical and electronic devices has significantly increased in recent years and the quantity of originated waste disposed of is consequently rising. WEEE (also called e-waste) is one of the fastest growing solid waste streams around the world. Its annual growth rate is 3 to 5%, which is approximately three times faster than other individual waste streams (Schwarzer et al., 2005).

Globally, 20 to 50 million tonnes of WEEE are generated per year (Schwarzer et al., 2005). According to Mallawarachchi & Karunasena (2012), these amounts represent 1 to 3% of global municipal waste production.

It is a major challenge that WEEE are mixtures of both different types of hazardous substances and, at the same time, valuable materials. In fact, due to the presence of high toxicity substances, such as heavy metals and flame retardants, the Basel Convention has classified WEEE as hazardous waste to be carefully controlled.

On the other hand, precious resources, in particular valuable metals and rare earth elements are consumed for their production, and are potentially recoverable if suitable collection and recycling schemes are put in place. In the high-grade WEEE fraction (see section II for definitions), the most valuable metals present are copper, gold, nickel, palladium and silver. After being collected, pre-treated and separated from other materials, the target metals can be processed as secondary resources in a metallurgical treatment facility (Bigum et al., 2011).

The European Union designated WEEE as a priority stream in the year 1991 and then started elaboration of legislation for a better management of e-waste, but it was only in 2003 that regulations came into legislative effect (Khetriwal et al., 2011). In order to address the challenges related to e-waste, the European Commission proposed, in 2002, two different regulatory elements: the WEEE Directive and the RoHS Directive (Directive on Restriction of Hazardous Substances). Both entered into force one year later, in 2003 (see Section III). In the revised versions that are presently in place, the two directives form the basis for current WEEE management in EU member states.

The aim of this paper is to elaborate an overview on the current EU regulatory framework for WEEE management and to present responses towards increased sustainability in the field of EEE. As part of the studied context, the paper explores producer responsibility as guiding principle and analyses its fulfilment in the context of WEEE management as an example of practical implementation of the concept. European Recycling Platform is presented as a pioneer in breaking monopolistic compliance schemes. Finally, a spotlight is set on hackerspaces (makerspaces), to highlight that consumer-initiated bottom-up approaches are still an emerging element in WEEE management, but with the potential to make a vital contribution to reducing e-wastes, while simultaneously

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strengthening the position of the consumer as pro-active participant in more sustainable use of electronic and electric equipment.

II. DEFINITION OF WEEE

There is no standard definition for qualifying WEEE. This is due to the fact that this term generally refers to any electrical and electronic equipment which the owner intends to discard, because it does no longer satisfy him for its original purpose. Any appliance using an electric power supply and which has reached its end of life can therefore be considered WEEE (Organization for Economic Co-operation and Development, 2001).

WEEE includes equipment of daily use such as computers, TV-sets, refrigerators and phones, but also lighting, electric and electronic tools, medical devices and others. The wide variety of appliances usually results into different management schemes for different devices. The WEEE Directive classifies WEEE into 10 categories (Table I).

TABLE I. WEEE CATEGORIES DEFINED IN THE EU DIRECTIVE (WEEE DIRECTIVE, 2012)

Number	Category name and examples of equipment
1	Large household appliances (Refrigerators and freezers, washing machines, clothes dryers, electric cookers, ovens and hobs, air conditioning units etc.)
2	Small household appliances (Vacuum cleaners, carpet sweepers, irons, toasters, fryers, coffee machines, electric knives, body care appliances, clocks etc.)
3	IT and telecommunications equipment (Computers, printers, copying equipment, facsimile equipment, telephones, calculators)
4	Consumer equipment (Televisions, video recorders and DVD players, video cameras, audio equipment, radio sets, musical instruments)
5	Lighting equipment (Luminaries for fluorescent lamps with the exception of luminaries in households, straight and compact fluorescent lamps, high intensity discharge lamps, low pressure sodium lamps etc.)
6	Electrical and electronic tools (Drills, saws, sewing machines, equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal etc.)
7	Toys, leisure and sports equipment (Electric trains or car racing sets, hand-held video game consoles, video games, computers for biking, etc., sports equipment with electric or electronic components, coin slot machines etc.)
8	Medical devices (Radiotherapy equipment, cardiology and dialysis equipment, pulmonary ventilators, nuclear medicine, analysers etc.)
9	Monitoring and control instruments (Smoke detector, heating regulators, thermostats, measuring, weighing or adjusting appliances for household or as laboratory equipment etc.)
10	Automatic dispensers (Automatic dispensers for hot drinks, hot or cold bottles or cans, solid products, money etc.)

These ten WEEE categories are commonly treated in six different ways, allowing to identify individual "treatment categories" (Huisman et al., 2007). Bigum et al. (2011) rearranged the categories as shown in Table II. It is possible to notice that WEEE Directive category 5 has been subdivided in two: luminaries (5a) and lamps (5b).

TABLE II. TREATMENT CATEGORIES DEFINED BY BIGUM ET AL. (2011)

Treatment categories	Categories of EEE
Large equipment	1, 10
Cooling white goods	1
Small WEEE: low-grade fraction	2, 5a, 6, 7, 8, 9
Small WEEE: high-grade fraction	3, 4
TV and monitors	3, 4
Lighting equipment	5b

The definition of categories listed in Table II allows a further characterisation of WEEE that emerges in the equipment recycling phase, that is high-grade or low-grade fraction. The difference is that high-grade fraction is richer on precious metals, available to be recovered if suitable collection and processing schemes are in place. This characteristic is appropriate for equipment falling in categories 3 and 4 of WEEE Directive (Bigum et al., 2011).

III. ROHS DIRECTIVE AND WEEE DIRECTIVE, EU WEEE

The RoHS Directive (2002/95/EC), revised in 2008 (2011/65/EU), is about the restriction of the use of certain hazardous substances, such as lead, cadmium, mercury, chromium, polybrominated biphenyls and other dangerous compounds, in electrical and electronic equipment. These substances are commonly found in WEEE and need to be substituted by safer ones in new electrical and electronic equipment (RoHS, 2011). By placing a product on the market, a producer declares that the product complies with the directive. The scope of this directive, with view to the equipment that falls under it, is the same of the WEEE Directive (see Table I).

The aim of the first WEEE Directive (Directive 2002/96/EC) was the promotion of WEEE re-use, recovery and recycling, as well as their reduction before the disposal phase. This could be practically implemented through the creation of collection and recycling systems, separated from the unsorted municipal solid waste stream, allowing a return free of charge for the consumer.

Moreover, the directive set targets for WEEE collection, as well as targets for recovery, re-use and recycling in EU Member States. For instance, the directive required that each one achieved a collection target of 4 kg of WEEE per capita, per year from private households.

The collection rate is an indicator that monitors how much WEEE are collected with respect to the electrical and electronic equipment put on the market. Calculating the collection rate for European countries, for which all data are available, it is possible to have an estimate of the level of improvement in managing WEEE. Collection rates and recycling rates in the EU countries are regularly published as Eurostat data (for latest data: Eurostat, 2015a; 2015b). The average rate for 26 European countries in 2010 was of 37% by weight (European Environment Agency, 2013; Kunz et al., 2014), a considerable increase if compared with the 23% realized four years before, in 2006 (with data from 22 countries). Considering the WEEE

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Directive requirement of 4 kg of waste from households per person per year, 20 of 26 EU member states in 2010 reached the collection target, while in 2006 only 11 countries out of 22 respected the requirement (European Environment Agency, 2013).

Data indicate also that even if the level of collection is still very low in many countries, the WEEE that are collected are largely re-used and recycled, as in 2010 already most EU countries achieved a reuse and recycling rate above 80% (European Environment Agency, 2013).

In 2012, the quantitative targets became more ambitious with the introduction of the revised WEEE Directive (2012/19/EU), turned effective in 2014.

This second directive, apart from some derogations, expects until the end of 2015 a minimum rate of separate collection from households of 4 kg per capita per year, while from 2016 to 2018 a collection rate of 45% and from 2019 a rate higher than 65%. The percentages refer to the average weight of electrical and electronic equipment placed on market in the country, in the three preceding years.

IV. Producer Responsibility

The WEEE Directive supports and fosters the "Producer Responsibility" principle, based on making the producer responsible for the management of the product that becomes waste (Shao & Lee, 2009). Implementation of the principle means that the producers are assigned financial and managerial responsibility for recovery and recycling of the goods they put into market. In this context, 'producer' is the entity that first placed a product on a national market, and can therefore be a manufacturer, an importer, a distributor or a retailer.

Producer Responsibility has been established as policy principle since the 1990s. The concept of "Extended Producer Responsibility" (EPR) as a market-oriented approach was coined in the early 1990s in Sweden, as the result of consultative cooperation between academia and government. Thomas Lindquist and Karl Lidgren introduced the principle of EPR in 1990 in a report to the Swedish Ministry of the Environment (Lindhqvist & Lidgren, 1990), and the principle was subsequently elaborated further in the following years. Since it was soon perceived as being a powerful approach for policies focusing on environmental impacts across product life-cycles, EPR was rapidly promoted in the 1990s by various institutions, including the OECD (Organisation for Economic Co-operation and Development).

EPR extends responsibility of the producer to the collection, recovery and final disposal phases of a product, therefore achieving a life-cycle perspective. This stimulates manufacturers to foster more innovative design of durable products and motivates to invest and to keep waste cost down by producing easily and cheaply recyclable goods. In this sense, introduction of this principle supports closing the whole product life-cycle by introducing a connection between the design and the recycling/re-use phases (Shao & Lee, 2009).

One shortcoming is that the EPR concept presupposes that producers are responsible for WEEE of all brands, which results into inequities in costs. For instance, a producer that invests a lot in the design phase, would pay in any case high recycling costs due to other manufacturers that did not give the same importance to the product design and, at the end, this does not stimulate improvements in innovation (Shao & Lee, 2009).

In order to overcome this problem, the "Individual Producer Responsibility" (IPR) concept was introduced in the 2000s. The difference of this approach is in the fact that each producer is responsible of the own-branded products only (Shao & Lee, 2009; European Recycling Platform, 2015). The practical implementation of the IPR represents a big challenge due to the fact that it is not so easy to sort EEE waste by brand, in order to determine the producer's share of financial responsibility (Shao & Lee, 2009). IPR is the targeted approach of the current EU regulations, although current implementation of the producer responsibility principle is in practice often applied closer to EPR than to IPR, which remains a field of development and necessary progress.

V. European Recycling Platform

European Recycling Platform (ERP) today provides producer compliance for waste electrical and electronic equipment (WEEE), batteries and packaging to more than 2,500 member companies in more than thirty countries (European Recycling Platform, 2015). ERP was originally created in 2002 by Braun, Electrolux, Hewlett-Packard and Sony in order to implement the EU WEEE Directive. This established the first ever pan-European producer compliance scheme. ERP provided an alternative concept to national monopolistic waste collection and recycling organisations, therefore introducing competition and enabling market principles in this area. This served as catalyst to the development of competitive compliance schemes throughout Europe and within the individual European countries and resulted in significant reductions of recycling costs, causing financial benefits for producers, consumers and ultimately national economies (Butler, 2009; Shao & Lee, 2009).

Through the WEEE Directive, responsibility to organise recovery and recycling of WEEE is assigned to the producers, while for the consumers the return has to be free of charge. Due to the transposition into the national laws of the EU member states, each country has different authorities and regulations, which creates differing obligations for producers active in several European countries. According to the EU Directive, producers do not need to manage the waste themselves, but can make use of compliance schemes that ensure collection, treatment and recycling. When the EU WEEE Directive was passed, some countries (Belgium, the Netherlands and Sweden) already had in place mandatory take-back of household WEEE (Shao & Lee, 2009). Monopolistic organisations took over the obligation of individual producers against payment of fees. Similar national monopolistic organisations existed for other waste streams, in particular the Green Dot system for handling packaging materials (Germany, Belgium, the Netherlands, Sweden, other countries) (Shao & Lee, 2009).

The founding members of European Recycling Platform introduced procurement of WEEE collection and recycling services on a European level, thus not only facilitating compliance with differing national regulations but also creating

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cross-border competition in the waste management market. Breaking the paradigm of monopolistic national compliance schemes and applying principles of being lean, outsourced and cost-effective, resulted into drastic reductions of recycling costs throughout Europe very soon after ERP became operational (Butler, 2009; Shao & Lee, 2009). Some recycling costs dropped to only one-tenth of their former level within very few years. To foster implementation of Individual Producer Responsibility, ERP also funded waste sampling studies in several countries and promoted developments of waste tracking technologies (Butler, 2009).

ERP today has an average market share of around 15% in WEEE management and recycling across Europe (European Recycling Platform, 2015). This level of market share both ensures competition and enables economy of scale (Butler, 2009). As of February 2015, ERP has processed around 2.5 million metric tons of WEEE (European Recycling Platform, 2015). The company has extended the scope of its services to batteries and packaging, and in addition to its primary focus on Europe, also became active in non-EU countries such as Turkey an Israel. It manages compliance for more than 2,500 companies under different service agreements. The portfolio includes national compliance services to meet the obligations in individual countries, and a European service package to provide a single point of contact and multi-country service agreements for producers with compliance obligations in several countries. The portfolio also offers compliance services for photovoltaic producers. According to the revised WEEE Directive (2012 - regulations to come into effect in 2014), photovoltaic module collection and recycling are now subject to producer responsibility.

The company has a relatively small number of employees (around one-hundred) and implements a lean structure that preferentially outsources key services to general contractors, which enables operational flexibility and competitive advantages. The company's policies (European Recycling Platform, 2015) contain commitments to be self-financing, to ensure highest quality and environmental standards, to apply fully transparent pricing mechanisms, to promote cost-efficient and innovative recycling strategies and to foster competition in the waste management services market.

ERP is regularly mentioned in various contexts as one of the best-performing compliance schemes. It certainly is a pioneer reference in successfully initiating and driving competition in the compliance scheme market, and in translating producer responsibility into pan-European and both custom-tailored and environment-oriented compliance solutions.

VI. HACKERSPACES

Electric and electronic devices functioning is generally complex and intricate so that, in case of malfunctioning, the owner prefers to get rid of instead of trying to repair it. For this reason, the amount of potentially repairable equipment that are discarded is increasing. In response to this negative trend, physical community clubs emerge with the purpose of helping in repairing devices and, in general, sharing expertise. These networks are called "hackerspaces" or "makerspaces" and actualize in dedicated places where people can meet to exchange information and receive technical assistance (European Commission, 2015).

Considering all disciplines, there are currently around 2,000 hackerspaces (both active and planned) all around the world (Hackerspaces wiki, 2015). In the context of WEEE, some examples are the Restart Project in London, the TechShop Project in the United States and the Largo City Makerspace in China (EC, 2015; Hackerspaces wiki, 2015).

The Restart Project is born from the evidence that many devices were discarded because their running was too slow and it was easier to buy new ones. The project is based on a group of volunteers that help people repairing their own equipment, that in most cases consists in home devices like computers, televisions etc.. Furthermore, the initiative organizes community events and is registered as Charitable Incorporated Organization (European Commission, 2015; The Restart Project, 2015).

A different example is represented by the TechShop Project, where professional equipment like laser and waterjet cutters, plastics and electronics labs, welding stations, are made available for members. A member of technical staff offers experience and expertise to encourage innovative designs and organizes courses for skills improvement. Members pay monthly or annual fee and have access to all facilities and software (TechShop Inc., 2015).

The Largo City Makerspace is located in Beijing and gives support to logistic and products promotion. As in other similar projects, mechanic and electronic devices are provided to the members, but training and support are implemented online (Largo City Makerspace, 2013).

Not only the number of initiatives is growing further worldwide, in addition, the variety of individual solutions is high. A common element however is, that it is the individual consumer who is motivated to get engaged to address the problem of e-waste reduction, embedded in a community context with transfer and build-up of skills.

VII. CONCLUSIONS AND OUTLOOK

The increase in the use of electrical and electronic devices has led and further leads to a growing quantity of resulting waste to be managed and a consequent concern related to their hazardousness, while at the same time there is high awareness that WEEE contain precious potentially exploitable resources.

In the European Union, WEEE Directive and RoHS Directive have shaped a framework to reduce environmental burden caused by waste from electric and electronic. A good example of implementation of the EU WEEE Directive and, at the same time, of the producer responsibility principle is represented by the European Recycling Platform, that involves several companies and provides higher performance compliance schemes for WEEE.

Basic regulatory frameworks remain to be elaborated and introduced in many regions worldwide in order to advance towards schemes that not only foster avoidance of environmental pollution and health burdens, but also enable recuperation of materials for further valorisation as secondary

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resources. Collection and recycling practices need to be given further attention (Alsheyab & Kusch, 2013), under consideration of the fact that the situation and requirements vary very much worldwide (Widmer et al., 2005). Challenges remain to be resolved even in regions with an advanced status in WEEE management. Recuperation of components with specific importance for the current, but especially the future economy, such as rare earth elements, is still an emerging issue, which will require major efforts in research and development.

Assessments and endeavours in the field of WEEE management are largely dominated by focusing on regulatory elements and recycling practices. The individual consumer is generally less in focus. Consumer-initiated initiatives such as hackerspaces provide evidence that individual members of society respond to the challenge of continuously growing WEEE occurrence in a pro-active and very promising way. Encouraging such responses from civil society seems highly desirable in view of huge WEEE material flows, and remains to be put on respective policy agendas as a priority.

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