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Mass balance and life cycle assessment of the waste electrical and electronic equipment management system implemented in Lombardia Region (Italy)

L. Biganzoli *, A. Falbo, F. Forte, M. Grosso, L. Rigamonti

Politecnico di Milano, Department of Civil and Environmental Engineering, Piazza L. da Vinci 32, 20133 Milano, Italy

HIGHLIGHTS

- The WEEE management system in Lombardia Region in 2011 was analysed in an LCA study.
- Primary data were collected to model the WEEE treatment.
- A detailed mass balance for each WEEE category was determined.
- Results show the good environmental performance of the system.
- The recovery of metals, plastic and glass gives the main benefits.

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ABSTRACT

Waste electrical and electronic equipment (WEEE) is one of the fastest growing waste streams in Europe, whose content of hazardous substances as well as of valuable materials makes the study of the different management options particularly interesting. The present study investigates the WEEE management system in Lombardia Region (Italy) in the year 2011 by applying the life cycle assessment (LCA) methodology. An extensive collection of primary data was carried out to describe the main outputs and the energy consumptions of the treatment plants. Afterwards, the benefits and burdens associated with the treatment and recovery of each of the five categories in which WEEE is classified according to the Italian legislation (heaters and refrigerators — R1, large household appliances — R2, TV and monitors — R3, small household appliances — R4 and lighting equipment — R5) were evaluated.

The mass balance of the treatment and recovery system of each of the five WEEE categories showed that steel and glass are the predominant streams of materials arising from the treatment; a non-negligible amount of plastic is also recovered, together with small amounts of precious metals. The LCA of the regional WEEE management system showed that the benefits associated with materials and energy recovery balance the burdens of the treatment processes, with the sole exception of two impact categories (human toxicity-cancer effects and freshwater ecotoxicity). The WEEE categories whose treatment and recovery resulted more beneficial for the environment and the human health are R3 and R5. The contribution analysis showed that overall the main benefits are associated with the recovery of metals, as well as of plastic and glass. Some suggestions for improving the performance of the system are given, as well as an indication for a more-in-depth analysis for the toxicity categories and a proposal for a new characterisation method for WEEE.

Abbreviations: ABS, acrylonitrile butadiene styrene; CED, Cumulative Energy Demand; CFC, chlorofluorocarbon; CH, Swiss context; CRTs, cathode ray tubes; DE, German context; EI, ecoinvent; FPDs, flat panel displays; FU, functional unit; GLO, global context; IT, Italian context; LCA, life cycle assessment; LCD, liquid crystal display; LCIA, life cycle impact assessment; LHV, lower heating value; MFA, material flow analysis; MMA, methyl methacrylate; NiMH, Nickel Metal Hydride; O.R.SO., Osservatorio Rifiuti Sovraregionale (regional waste observatory); PEF, product environmental footprint; PET, polyethylene terephthalate; PMMA, poly(methyl methacrylate); PS, polystyrene; PWBs, printed wiring boards; R1, heaters and refrigerators; R2, large household appliances; R3, TV and monitors; R4, small household appliances; R5, lighting equipment; RER, European context; UCTE, Union for the Co-ordination of Transmission of Electricity; UM, unit of measure; WEEE, waste electrical and electronic equipment.

* Corresponding author.
E-mail address: laura.biganzoli@mail.polimi.it (L. Biganzoli).

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1. Introduction

Waste electrical and electronic equipment (WEEE) is one of the fastest growing waste streams in Europe, with a growth rate of approximately 3–5% per year (European Commission, 2014). Due to the presence of hazardous substances, such as heavy metals (for example, mercury and lead in fluorescent lamps and batteries) and flame retardants, if improperly managed it might pose significant human health and environmental risks (Tsydenova and Bengtsson, 2011). On the other hand, it must be regarded as an important source of valuable materials, because of the presence of plastics, glass, base and precious metals, and rare earth elements that can be recovered (Cui and Zhang, 2008; Tuncuk et al., 2012). For example, precious metals such as gold and palladium occur in concentration more than tenfold higher in printed wiring boards (PWBs) than in commercial mined minerals (Betts, 2008).

For all the above mentioned reasons, the interest in the WEEE treatment and recovery has largely increased in recent years, and several papers have been published regarding specific WEEE streams and their treatment options. For example, Li et al. (2007) investigated the possibility to recover the PWB by means of mechanical treatments including a shredding stage and the separation of the metallic fraction through a corona electrostatic separation process. Mechanical processes are widely used for WEEE disassembly and for the separation of the metallic fractions. An extended analysis of the mechanical processes available for WEEE treatment was carried out by Cui and Forssberg (2003), showing that in order to achieve the maximum recovery of the materials, WEEE should be shredded to small particles, generally below 5 mm or 10 mm. Material recovery from WEEE is not restricted to the sole metallic fraction. Plastic and glass can be also recovered. For example, Andreola et al. (2007) investigated the possibility to reuse the glass separated from cathode ray tube (CRT) TV and monitors in the ceramic glaze industry and estimated the environmental performance of this practice.

Life cycle assessment (LCA) is a fundamental tool to assess the environmental benefits and burdens associated with waste management. However, up to now, LCA studies involving WEEE have typically been applied on a single product, eventually including focuses on different management alternatives (Andrea and Andersen, 2010; Johansson and Bjorklund, 2009; Lu et al., 2006; Park et al., 2006). Comprehensive studies assessing the environmental benefits and burdens of the overall WEEE collection and recovery system at a regional or national level are hardly available. Hischier et al. (2005) examined the two WEEE take-back and recycling systems implemented in Switzerland and defined their environmental impacts by means of a combined approach of material flow analysis (MFA) and LCA. The study was then updated by Wäger et al. (2011), by introducing new treatment options and improving the dataset used for the modelling of the treatment of the various WEEE fractions.

In Italy, WEEE is classified in five categories (DM n. 185 of the 25th of September, 2007): heaters and refrigerators (R1), large household appliances (R2), TV and monitors (R3), small household appliances (R4) and lighting equipment (R5). Their separate collection started in 2005, when the European legislation (Directives 2002/95/CE, 2002/96/CE and 2003/108/CE) was implemented by means of the national Decree 151/2005. In 2011, an average of 4.7 kg of WEEE per capita was collected in Lombardia Region (Centro di Coordinamento RAEE, 2011).

This study is a part of a wider research project involving Regione Lombardia. The first part focused on municipal solid waste, whose management system was analysed by means of LCA in order to assess the current situation and to give useful strategic indications for future waste management (Rigamonti et al., 2013a, 2013b). The second part, which is described in the current paper, focused on the WEEE stream.

The research investigates the WEEE management system in Lombardia Region in the year 2011 by applying the LCA methodology. Contrary to previous studies (Hischier et al., 2005; Wager et al., 2011), the analysis was carried out on each of the five WEEE categories, as well as on the overall WEEE management system. An extensive collection of primary data was carried out to assess the mass balance of the treatment plants; the benefits and burdens associated with the treatment and recovery of each category were then evaluated. Results obtained separately for the five categories were finally used to assess the environmental performance of the overall WEEE management system implemented in the Region and to identify potential for improvements.

The level of detail of the assessment allows extrapolating the findings to other European regions, at least for a first screening of the WEEE management system.

2. Materials and methods

The study was carried out to quantify the mass balance of the WEEE management system in Lombardia Region in the year 2011 and to assess its environmental benefits and burdens following an LCA approach. The five WEEE categories were analysed separately, and then the results were merged in order to get the complete picture of the WEEE management scheme. Overall 46.070 tonnes were collected in 2011 in Lombardia Region, split as follows: 21.4% of R1, 21.1% of R2, 36.5% of R3, 20.4% of R4 and 0.6% of R5 (Centro di Coordinamento RAEE, 2011).

The LCA methodology was applied in all its four basic stages (ISO, 2006): goal and scope definition, inventory analysis, impact assessment and interpretation. The assessment was carried out with the support of the SimaPro (version 7.3.3) software. For each unit, a new module was designed, including the energy and material consumption, the direct emissions as well as the substituted materials and energy, with the same approach adopted in previous studies (Rigamonti et al., 2010, 2013a, 2013b).

2.1. Goal and scope definition

Three are the goals of the study:

1) the evaluation of the mass balance of the treatment and recovery system of the five WEEE categories defined by the Italian legislation;
2) the assessment of the environmental performance of the treatment and recovery system of each WEEE category, with the aim to understand if the benefits arising from the material and energy recovery are offsetting the burdens due to the processing of the waste itself;
3) the evaluation of the environmental performance of the overall WEEE management system implemented in Lombardia Region in the year 2011.

The results of the study were used to support the regional authorities in the identification of the critical aspects of the current WEEE management system and of its possible improvement.

The functional unit (FU) was defined as 1 tonne of collected WEEE for each of the five categories. Waste composition is not known in terms of type of equipment (e.g., for R4 the presence of each type of appliances in 1 tonne), but it could be assessed on the basis of the outputs of the first treatment plants, in terms of recovered components (e.g., batteries and motors) and materials (e.g., plastics, aluminium and ferrous metals). In fact for a very heterogeneous waste stream such as WEEE (and the R4 category in particular), a characterisation based on the outputs of the first treatment plants turned out to be more representative and more relevant from a recovery perspective, than the traditional analysis of the waste input composition.

The system boundaries include all the treatment processes, from the moment the waste is collected to when it leaves the system as an emission (solid, liquid or gaseous) or as a secondary raw material, following the "zero burden assumption" (Ekvall et al., 2007). They thus included the collection of the waste, its transport to the collection platform, the pre-processing (here referred to as "first treatment plant") and the subsequent treatment of the separated components in the final recycling/disposal plants, as shown in Fig. 1.

The geographical scope of the study was regional and the study focused on conditions and technologies for 2011 (i.e., the WEEE