Waste Management 34 (2014) 468–474

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Environmental burdens in the management of end-of-life cathode ray tubes

Laura Rocchetti, Francesca Beolchini *

Dipartimento di Scienze della Vita e dell'Ambiente, Università Politecnica delle Marche, Via Brecce Bianche, 60131 Ancona, Italy

ARTICLE INFO

Article history:
Received 13 May 2013
Accepted 16 October 2013
Available online 15 November 2013

Keywords:
End-of-life CRT
Recycling
Life-cycle assessment
Environmental impacts
Yttrium

ABSTRACT

We compared the environmental burdens in the management of end-of life cathode ray tubes (CRTs) within two frameworks according to the different technologies of the production of televisions/monitors. In the first case, CRT recycling is addressed to the recovery of the panel and funnel glass for the manufacturing of new CRT screens. In the second case, where flat screen technology has replaced that of CRT, the recycling is addressed to the recovery of the glass cullet and lead for other applications. The impacts were evaluated according to the problem-oriented methodology of the Institute of Environmental Sciences, Leiden University, Leiden, The Netherlands. Our data confirm that in both cases, the recycling treatment allows benefits to be gained for the environment through the recovery of the secondary raw materials. These benefits are higher for the "CRT technology" framework (1 kg CO_2 saved per CRT) than for the "flat screen technology" (0.9 kg CO_2 saved, per CRT, as the highest possible), mainly due to the high energy consumption for lead separation from the funnel glass. Furthermore, the recovery of yttrium from the fluorescent powders that are a residue of the recycling treatment would further improve the CO_2 credit for both the frameworks considered, which would provide a further saving of about 0.75 kg CO_2 per CRT, net of the energy and raw materials needed for the recovery.

Overall, this study confirms that, even with a change in the destination of the recovered materials, the recycling processes provide a benefit for the environment: indeed the higher loads for the environment are balanced by avoiding the primary production of the recovered materials.

1. Introduction

In the world of today, and at least in the industrialised areas rather than in the developing countries, the habit of the repair, re-use and recycling of goods is disappearing, often because the repair of a component that does not work has a cost that is comparable to the purchase of the new item. This is especially true for electrical and electronic equipment (EEE). In addition to this reason, another important aspect that enhances this phenomenon is the rate of evolution of new technologies that become available on the market. This pushes the consumer to buy the latest version of an EEE, and the old one is discarded, although it might sometimes still be working. In Europe, contrary to the consumerist habits of the people, the WEEE Directive (Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment, WEEE) supports the "re-use, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste and to contribute to the efficient use of resources and the retrieval of valuable secondary raw materials". Furthermore, the WEEE Directive sets minimum recovery targets for the various WEEE categories. For example, according to the Directive, 75% of computers and television sets should be recovered, and 65% should be recycled by 14 August 2015.

The WEEE Directive also establishes that from the WEEE collected separately, at a minimum, the cathode ray tubes (CRTs) must be removed, as well as the fluorescent powders inside these. Fluorescent powders contain metals of concern, such as yttrium, which can be recycled as a secondary raw material (Beolchini et al., 2012). Indeed yttrium used for the red phosphors of monitors is mainly mined in China, where the biggest reserves are located, and it has been estimated that in 20–30 years, these reserves might run out of this rare earth metal (OECD, 2010; USGS, 2013). Therefore its recycling is of great importance.

At present, CRT technology for televisions and computers is obsolete, and it is being replaced mainly by plasma display panel (PDP), liquid crystal displays (LCD) and light-emitting diodes (LED) flat panel screens (Hischier and Baudin, 2010). In the developed nations, at least, it is now impossible to find a CRT computer monitor or television in electronic shops. However, they are still present in the houses of many people, and they are gradually being replaced by new flat screens. Based on WEEE collection and

* Corresponding author. Tel.: +39 071 2204225; fax: +39 071 2204650.
E-mail address: f.beolchini@univpm.it (F. Beolchini).

0956-053X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.wasman.2013.10.031

pre-treatment market, about 50,000–150,000 tons/year of end of life CRTs are currently collected within Europe and this flux is not expected to decrease in the next years. In Europe, the end-of-life of CRTs occurs according to the WEEE Directive. Until about 10 years ago, when CRTs were still produced, glass-to-glass recycling was a feasible option (Kang and Schoenung, 2005). This consisted of the use of parts of waste CRTs (i.e., glass, metals, plastic) for the manufacturing of new CRTs, in a closed-loop process. In particular, the parts that were mostly recycled were the funnel and panel glass. The panel glass, which is the front part of the display, is essentially barium-strontium glass, with a low percentage of lead (Andreola et al., 2007a). The funnel glass is the back conical part of the CRT, which is mostly made of glass and lead, as it was used to shield against the X-rays produced inside the CRT. Lead is present at high concentrations in the funnel glass (lead oxide can be up to *ca.* 20%; Andreola et al., 2007b), and it is a hazardous compound that can pose risks for the environment if it is not correctly handled. In this regard, previous studies have been carried out to determine the leachability of lead from CRTs in landfill sites, and to have an idea of its potential risks as a hazard (Jang and Townsend, 2003; Nnorom et al., 2011).

To minimize the amount of waste destined for landfill sites, efforts need to be directed towards the recycling options. Now that the previous glass-to-glass recycling is no longer a feasible option, glass-to-lead recycling represents an alternative strategy. Processes for the removal of lead from funnel glass have been developed and are currently being applied in the UK by the SWEEEP Kuusakoski Facility (http://www.sweepkuusakoski.co.uk/glassrecycling/ (accessed 26.04.2013)). In this facility, a furnace that works at 1200 °C recovers lead from glass, with a capacity of 10 tonnes of funnel glass per day. Consequently, through smelting at high temperatures, the lead is separated from glass, and the glass can be recycled for different uses in the glass and ceramic industries (Andreola et al., 2008, 2009, 2010). The fluorescent powders are another part of CRTs that requires particular attention for handling and disposal. These form a layer inside the panel glass, which can be removed easily. At present, their recycling is not carried out by recycling companies, and once they are removed they are disposed of in landfill sites for hazardous materials (Lee and Hsi, 2002; Nnorom et al., 2011). Our research group has developed a cost-effective recycling process for the recovery of rare earth elements, carried out within the European HydroWEEE 231962 research projects (Innovative Hydrometallurgical Process to Recover Metals from WEEE, Including Lamps and Batteries), and its follow-up, HydroWEEE Demo 308549 (Toro et al., 2010; Rocchetti et al., 2013).

The present study was aimed at the assessment of the environmental impact of different options for end-of-life CRTs through a simplified life-cycle assessment (LCA). Some estimates of the environmental loads/benefits of WEEE recycling have already been given in the literature (Hischier et al., 2005; Gamberini et al., 2010; Wäger et al., 2011) also dealing specifically with the end of life CRTs management (Andreola et al., 2007a; Song et al., 2012). This study is addressed at the comparison of several scenarios for CRT recycling, from the more conservative ones, to the most innovative ones, with all in accordance with the principles of the WEEE Directive. Two main frameworks for the management of end-of-life CRT have been taken into consideration: (i) conventional recycling for the production of new CRT monitors; (ii) recycling of the CRT components for other purposes that are feasible in the flat screen era. The disposal in landfill sites for hazardous waste has also been taken into consideration, as the present baseline. Indeed, the study did not exclude that in the change in the destination of the recovered materials – and consequently in the processes applied – the recycling itself might have too high a load for the environment.

2. Materials and methods

2.1. Goals and scope

2.1.1. Objective of the study

The main goal of the present study is a comparison of the environmental impacts of two different frameworks for the management of end-of-life CRTs. In particular, the impacts of conventional recycling (when CRTs were produced on a large scale) and more recent recycling (when CRTs are considered obsolete and are being replaced by the flat screen technology) of CRTs are considered. These scenarios are also compared to the disposal in landfill sites of end-of-life CRTs. Deeper consideration is addressed to the recycling of yttrium from the fluorescent powders, which exploits a process developed by the authors and coworkers (Rocchetti et al., 2013), as compared with the disposal of the powders in a landfill site for hazardous materials.

2.1.2. System boundary

Two main frameworks for the end-of-life CRT were taken into consideration: (i) conventional recycling of the steel, funnel and panel glass for the production of new CRT monitors, and disposal of the other parts (the "CRT technology"; scenario 1); (ii) recycling of the CRT components for purposes different from new CRT monitors ("flat screen technology"), on the one hand, with the recycling of the steel and panel glass (scenario 2), and on the other hand, taking the recycling also to the treatment of the funnel glass for the recovery of the lead and glass (scenario 3).

In scenario 2, glass cullet is produced from the panel glass, which is usable in the ceramics and glass industries (Andreola et al., 2007b). In scenario 3, the lead is recovered from the funnel glass through the use of a relatively new technology available on the market. The impacts determined by these two frameworks are compared with disposal in a landfill site for hazardous materials of the end-of-life CRTs (scenario 0). The "CRT technology" framework represents the old way of CRT recycling, when CRT monitors were routinely produced and when the steel, panel glass and funnel glass were recycled for new CRT production, as glass-to-glass recycling. The "flat screen technology" framework is an up-to-date recycling strategy, where CRTs are dismantled and most of the materials are recycled for purposes different from inclusion in new CRTs, in compliance with the WEEE Directive, as glass-to-lead recycling. In particular for the present study we refer to a smelting process carried out by the SWEEEP Kuusakoski Facility, that is assumed to be equivalent to a furnace at 1200 °C.

In the last part of the present study, attention is focused on the recycling of the fluorescent powders only. We have compared the impacts in terms of CO_2 emissions of a treatment addressed to yttrium extraction from fluorescent powders, with the impacts of the disposal of the fluorescent powders themselves in a landfill site for hazardous materials. The process for the yttrium recovery is based on sulfuric acid leaching and selective precipitation of yttrium as an oxalate salts. All of the details of the process are reported elsewhere (Rocchetti et al., 2013; Innocenzi et al., 2013a,b).

Manual dismantling (assumed to be without impact) of the several components, together with the cutting of the CRT itself using diamond cutting technology are included as treatments prior to the recycling phase. In the recycling scenarios, the treatments themselves and the production of the secondary raw materials and waste are included inside the system boundary. To compare the impacts of the recycling options, the disposal in a landfill site of the whole end-of-life CRTs is considered inside the system boundary. Fig. 1 provides a schematic representation of the management options for an end-of-life CRT. All the phases represented are also those considered for the evaluation of the impacts and the