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Recycling of electronic displays: Analysis of pre-processing and potential ecodesign improvements

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ABSTRACT

This article analyses the current and future end-of-life management of electronic displays (flat screen televisions and monitors), and identifies and discusses possible ecodesign recommendations to improve it. Based on an investigation of the treatment of displays in two typical European recycling plants, key aspects and criticalities of the recycling methods (sorting, dismantling and pre-processing) are identified. Disaggregated data concerning on-site measurements of the time needed to manually dismantle different displays are presented. The article also discusses the potential evolution of end-of-life scenarios for electronic displays and suggests possible recommendations for recyclers, producers and policy-makers to promote resource efficiency in the recycling of such waste products. Data on time for dismantling the displays can be used to build measurers for voluntary and mandatory policies, to stimulate design innovations for products improvement, and to assess possible alternative treatments of the waste during the pre-processing at the recycling plants. Some quantitative product measures (based on the time thresholds for dismantling some key components) are also discussed, including an assessment of their economic viability. These measures can potentially be enforced through mandatory and voluntary European product policies, and could also be extended to other product groups.

1. Introduction

Electric and electronic equipment (EEE) contain a wide range of substances, some of which are valuable, and some which are toxic or otherwise hazardous (Hagelüken, 2006). Components containing harmful substances (which would impair recycling efforts) or valuable substances (which retain their high value only when treated separately) should be easily identifiable in order to ensure that they are extracted and recycled (Wimmer and Züst, 2003).

Waste Electric and Electronic Equipment (WEEE) need to enter the appropriate mix of recovery processes, including sorting, dismantling and pre-processing (e.g. shredding) and end-processing (e.g. using pyrometallurgy, hydrometallurgy and electro-metallurgy) (Mathieux et al., 2008; Chancerel et al., 2009; Schluep et al., 2009). Selective dismantling is often recognised as an indispensable part of the recycling process because it allows for the selective extraction of hazardous components (Cui and Forssberg, 2003), a higher quality of valuable recyclable materials (e.g. engineering plastics) (Aizawa et al., 2008), and, as opposed to shredding, it allows for the re-use of parts (Kondo et al., 2003).

Mixing product parts of different compositions during the collection/pre-processing stages negatively influences the recycled yields (due to dilution or the technical constraints of some recycling processes) (Hagelüken, 2006). Chancerel et al. (2009) observed that unselective fine shredding can lead to the loss of valuable substances, including various rare and precious metals, contained in electronic components (especially printed circuit boards—PCBs). These losses occur due to the dispersion, after shredding, of mass-relevant fractions of valuable metals (e.g. plastics and ferrous metals). A comparison of recycling treatments of televisions (TVs) by Peeters et al. (2013) concluded that less than 10% of precious metals are recovered when mechanical treatments are used, while the manual dismantling of waste products allows for the recovery of more than 90% of such metals. Similarly, Meskers et al. (2009) concluded that up to 92% of the silver and 97% of the gold contained in the PCBs of EEE can be recovered in an economically viable way when these components are selectively extracted and sorted from other waste streams.

The content of precious metals in WEEE is relevant both for economic (Hagelüken, 2006; Peeters et al., 2013) and environmental

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reasons, as the manufacturing of these materials can have relevant lifecycle impacts (Ardente and Mathieux, 2012).

The recycling yields of scarce and precious metals from WEEE can be improved by an appropriate design of the product that facilitates the dismantling and sorting of components according to their material composition (Chancerel et al., 2011). WEEE should also be pre-processed in order to remove large iron and aluminium parts without causing the simultaneous loss of precious metals (Hagelüken, 2006).

As the dismantling process accounts for a large part of the costs of recycling, it is imperative to minimise the amount of work required for this stage (Willems et al., 2006). Furthermore, it has been estimated that large-scale dismantling can only be profitable and optimal when the time taken to dismantle a product is substantially reduced, in particular with regard to medium- and large-sized EEE and in products that are rich in valuable substances (Willems et al., 2006).

The need to improve the recovery of resources from the recycling of waste products and, in particular, WEEE, has been pointed out in various European policy initiatives (EC, 2011a; EC, 2011b). Policies promoting resource efficiency can be subdivided into two groups: policies that address waste treatment (end-of-pipe) (e.g. the Waste Directive (EU, 2008) and the WEEE Directive (EU, 2012)), and policies that focus on promoting cleaner production (e.g. the Ecodesign Directive (EU, 2009a) and the Ecolabel Regulation (EU, 2009b)). The first group sets the framework for the proper treatment of waste, while the second group focuses on requirements with which products should comply when being commercialised. In both groups, dismantlability has been highlighted as a key feature for the recyclability of products. For example, article 4 of the European WEEE Directive (EU, 2012) states that ecodesign requirements facilitating the dismantling of WEEE should be laid down in the product design in order to optimise the re-use and recovery of materials. The Ecodesign Directive (EU, 2009a) states the need to improve the dismantlability or products, for example by using various strategies such as the reduction of the number of materials and components used, or the reduction of the time and the complexity of tools needed to disassemble a product.

A recent study by Dalhammar et al. (2014) reviewed several studies on resource efficiency and its inclusion in policies. The study formulated various recommendations, including the need to establish pilot projects and research to examine the potential of cost-effectively recycling materials (with a special focus on critical materials), the need to establish research into new materials and better designs, and the need to develop new and well-designed product requirements through the timely introduction of new standards.

It is therefore necessary to carry out an analysis of the end-of-life (EoL) of EEE, with a special focus on dismantling processes, in order to improve a product's design so as to enhance its recyclability and to optimise the overall resource efficiency of EoL treatments. This can be promoted through policy measures that support good design practices (Mathieux et al., 2008), in synergy with other measures to improve the collection and recycling of waste (Bouvier and Wagner, 2011).

Resource efficiency of EEE can be promoted with the enforcement of some "push" and "pull" policy measures on "design for dismantling" (Dalhammar et al., 2014). In particular, the manufacturer could be "pushed" to achieve minimum performance levels (e.g. via the enforcement of Ecodesign measures for energy-related products), before introducing new products to the market. These measures would allow for the removal of products that are very difficult to dismantle (EU, 2009a). In addition, pro-active manufacturers could be encouraged ("pulled") to design high-performance products, e.g. via the introduction of specific criteria for environmental labelling (such as the EU Ecolabel (EU, 2009b)).

2. Aim of the article

The considerations discussed in the introduction concern all WEEE, particularly waste electronic displays (flat screen TVs and monitors) (Hagelüken, 2006; Ardente and Mathieux, 2012; Peeters et al., 2013).

With an estimated 30 million devices in the EU reaching their EoL by 2015, flat panel displays is a particularly significant waste category (Fakhredin and Huisman, 2013). In recent years, there has been much scientific interest in improving the design of this product category for recycling purposes (Dodbiba et al., 2008; Ardente et al., 2013; Peeters et al., 2014). Recycling with dismantling has been judged to be one of the most efficient strategies in treating waste displays (Shih et al., 2006).

Some policies already address design for the recycling of electronic displays. For example, the need for easy disassembly/dismantling[1] of electronic displays and for the extraction of some key components has been highlighted in some criteria for voluntary environmental product labelling, as in the European Ecolabel[2], the 'Blaue Engel'[3], and the 'Nordic Ecolabelling'[4] initiatives. However, these criteria are general and difficult to verify. A more specific and detailed criterion on design for dismantling electronic displays has been published by the Institute of Electrical and Electronics Engineers (IEEE)[5], although its application by manufacturers is only voluntary.

Additional measures could be enforced via mandatory policies, such as the European Ecodesign Directive (EU, 2009a). Annex I of this Directive states that the assessment of the ease of reuse and recycling of energy-related products (ErP) should consider the time necessary for disassembly and the ease of access to components containing valuable and recyclable materials, and hazardous substances. Measures based on 'time for dismantling' thresholds have not yet been enforced in European policies, although their application has been discussed in the scientific community (Ardente and Mathieux, 2014a) and in the policy debate (ECEEE, 2012).

This article presents a novel approach to identify workable and quantitative measures for the 'design for dismantling' of product based on an analysis of the pre-processing of electronic displays at recycling facilities. The approach starts from the 'on-site' analysis of two recycling plants (Section 3.1) to identify criticalities of the pre-processing stage in extracting key components from the displays. Potential future changes of the current recycling treatment methods are also assessed (Section 3.2). The time taken to dismantle displays is measured using 'on-site' disaggregated data (per size

[1] The terms 'dismantling' and 'disassembly' of a product (or its parts) are generally used as synonyms when referring to recycling processes. However, there is a slight difference between the two terms: the former mainly refers to the careful removal/extraction of the part (e.g. for substitution or repair), while the latter refers to the removal/extraction of the part in a way that could potentially destroy the functional integrity of the product.

[2] "The manufacturer shall demonstrate that the television can be easily dismantled by professionally trained recyclers using the tools usually available to them, for the purpose of: undertaking repairs and replacements of worn-out parts; upgrading older or obsolete parts, and separating parts and materials, ultimately for recycling" (EC, 2009).

[3] "The appliance shall be so designed and as to allow an easy and quick disassembly for the purpose of separating resource-containing components and materials" (der Blaue Engel, 2012).

[4] "The manufacturer shall demonstrate that the product can be easily dismantled [. . .] for the purpose of separating parts and materials, ultimately for re-cycling. [. . .] To facilitate the dismantling: fixtures within the products shall allow for this disassembly, e.g. screws, snap-fixes, especially of parts containing hazardous substances" (Nordic Ecolabelling, 2013).

[5] The time for dismantling the television for recycling shall be "at most 10 min for products weighting less than 50 lb (18.7 kg); and at most 10 min plus 1 min per each additional 5 lb (1.87 kg) of total product weight, for products weighting 50 lb or more" (IEEE, 2012).