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Life-cycle energy use and GHG emissions of waste television treatment system in China

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ABSTRACT

Waste electrical and electronic equipment (WEEE) has become one of the fastest growing solid waste. The development of WEEE treatment facility will promote the infrastructure to realize sustainable waste management. At present, the treatment of cathode ray tube televisions (TVs) forms the dominant part of the WEEE treatment system in China. In this paper, a life cycle assessment is conducted to estimate the energy use and greenhouse gas (GHG) emissions arising from CRT TV treatment. Three treatment scenarios for CRT TV are analysed: (i) the current situation in China (Current China Scenario), (ii) one with encouragement from China's WEEE Directive (WEEE Directive Scenario), and (iii) the development of more advanced techniques (Advanced Technique Scenario). The results show that the changes in energy use caused by the three scenarios are −526.51, −475, and −556.07 MJ, respectively. Meanwhile, the relevant GHG emissions are −19.59, −20.43, and −25.82 kg $CO_{2\text{-eq}}$, respectively. The scenario involving encouragement from China's WEEE Directive offers no benefit compared to the current situation in terms of energy use and GHG emissions. Moreover, the Advanced Technique Scenario is more efficient than the Current China Scenario. In consideration of the main contribution, the results reveal that CRT glass recycling contributes the highest energy use and GHG emissions to CRT TV treatment, besides, displaced plastic and displaced glass account for the main proportions with regard to any accrued environmental gain. A sensitivity analysis is also carried out to quantify the influence of collection efficiency and the lead (Pb) recovery rate on environmental performance. In so doing, some recommendations are proposed to realize the sustainable development of the WEEE treatment system in China.

1. Introduction

Advances in Information and Communication Technology (ICT), increasing consumption of electronic product, and growing spending power have resulted in fast growth in the amount of WEEE (i.e., e-waste) on a global scale (Umair et al., 2015; Milovantseva and Fitzpatrick, 2015). WEEE contains numerous recyclable materials and hazardous substances which makes its treatment an important environmental issue (Duygan and Meylan, 2015).

In China, the amount of discarded items among the five most common kinds of household appliances (television, washing machine, air conditioner, refrigerator, and computer) will increase from 130 million units in 2010–221 million units by 2020 (Zhang et al., 2012). At present, the dominant WEEE treated by the licensed plants is cathode ray tube (CRT) TVs. As is well-known, traditional CRT monitors are being replaced by liquid crystal displays (LCDs) and light-emitting diodes (Zhang et al., 2013; Savvilotidou et al., 2014). Therefore, a large number of conventional CRT TVs have been discarded, causing the amount treated to increase continuously. According to the Ministry of Environmental Protection (MEP), more than 70.45 million units of WEEE were treated by formal recyclers, including 57.63 million CRT TVs in 2014. The amount of CRT TVs discarded is predicted to decrease from 2018 and at least continue to do so until 2030 (Tian et al., 2014; Habuer et al., 2014). Thus, CRT TVs still attract attention in the overall environmental management of WEEE in China, and will do so for the long-term.

China's *Administration Regulation for Collection and Treatment of WEEE* establishes a multi-channel collection and centralized treatment system, and a qualification/permission system. It also proposed to establish a Fund Policy. Consequently, it is consid-

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ered as China's WEEE Directive (Ongondo et al., 2011). After being enacted, China's WEEE Directive promoted the development of WEEE treatment industry and provides guidance under which WEEE may be disassembled by licensed facilities. In particular, the treatment ratio of waste TVs by licensed plants had grown from 26% in 2010 (Song et al., 2012) to 90% in 2013 (Li et al., 2015a,b). China's WEEE Directive, and its supporting policies, encourage licensed plants to build a website-based collection system and to treat CRT funnel glass with lead smelting. As these approaches are emerging treatment options used for waste TVs, their potential environmental performance remains to be quantified.

The life cycle assessment (LCA) can be used to analyse the implications arising from the implementation of WEEE legislation (Dowdell et al., 2000; Nakano et al., 2007), environmental burdens of the allied collection and recycling systems (Hischier et al., 2005; Wäger et al., 2011), and the environmental benefits of recycling (Johansson and Björklund, 2009; Menikpura et al., 2014; Diener and Tillman, 2015). Regarding CRT TVs, the current LCA mainly pays attention to CRT monitors (Parsons, 2007; Rocchetti and Beolchini, 2014), especially CRT glass (Andreola et al., 2007; Xu et al., 2013). Also, research focuses on the effects that the update from CRT to LCD monitors will have on the treatment system thereof (Noon et al., 2011). In China, investigations have been conducted on licensed treatment plants (Hong et al., 2015; Song et al., 2013) wherein the functional unit is 1 t of WEEE (mainly includes TVs, washing machines, refrigerators, air conditioners, and computers). It is hard to determine the contribution of environmental impacts from waste CRT TVs, because the percentage of each WEEE component varies from plant to plant. Song et al. (2012) researched the environmental impacts of CRT TV during the end of life stage. The life cycle impacts of different methods: landfill, incineration, recycling by formal plants in China, and recycling in the EU are expressed with the endpoint indicator EI99 points as references. As the above studies cater for different scenarios which differ from the current waste TV treatment landscape, they cannot directly support decision-making.

This study identified typical treatment options for waste CRT TVs and determined whether, or not, the suggested recycling techniques could potentially result in environmental benefits. By using a rigorous LCA methodology, the environmental implications of the proposed China's WEEE Directive are quantified in comparison with current practices in China. Meanwhile, some advanced techniques, such as, website-based collection and bio-hydrometallurgical processing are also considered. Relevant results from this study could support decision-making for government sectors and enterprise managers, so that they could adjust their current policies on environmental management, and improve WEEE treatment techniques.

2. Method

The aim of this study was to explore the environmental implications of waste TV treatment, and identify the opportunities of different recycling techniques to improve WEEE management in China. To these ends, an environmental LCA was performed, with respect to life-cycle energy use and greenhouse gas (GHG) emissions.

The life-cycle energy consumption was measured by primary energy demand (MJ). The total GHG emissions were evaluated in terms of $CO_{2\text{-eq}}$ using 100-year Global Warming Potential (GWP) factors from the latest IPCC Fifth Assessment Report.

2.1. Functional unit

The functional unit was a single TV set, specifically a 29-inch colour CRT screen. According to a sampling analysis in licensed dismantling plant, the average composition of the TV was as follows: panel glass, 19.51 kg; funnel glass, 7.73 kg; mixed plastic, 5.45 kg; printed circuit board assembly (PCBA), 1.31 kg; fluorescent powders, 0.02 kg; and others (*i.e.*, steel, copper, glass), 6.03 kg.

2.2. Description of the technical systems

2.2.1. Collection and transport

Influenced by the long-term development of the waste collection industry, WEEE in China is currently collected in traditional ways. Collectors ride electric tricycles along streets to collect WEEE, which is then gathered and transported from disperse sites to transfer stations. After being trans-shipped many times, the WEEE is transported to special recycling plants.

In recent years, with the unceasing fusion between Internet technology and traditional industries, a WEEE online collection platform based on various websites has gradually appeared in China. In addition, it has become an important area of development and is supported by the government. In 2015, Green Eco-manufacture, the typical WEEE disassembling and recycling plant in China, officially launched its website-based collection project. This project aims to collect WEEE based on website and mobile APPs: it collects WEEE through online trading and uniform offline logistics as a template governing its operations. In addition, a batch of Internet companies dedicated to the collection of WEEE has gradually appeared, such as Aihuishou and Taolv.

Moreover, the National Development and Reform Commission (NDRC) issued their *Implementation Plan for Combining the Internet and Green Ecology in the next Three Years*. This policy makes the Ministry of Commerce (MC) responsible for promoting the waste collection industry in its transformation from a loose, extensive one, to an intensive, large-scale, benefit-oriented one by using information technology. Meanwhile, this policy encourages the waste collection industry to popularize its new website-based collection mode by acquiring, analysing, and monitoring information using the Internet of Things and big data.

2.2.2. Disassembly

Licensed treatment plants in China mainly use workers on assembly lines to manually disassemble CRT TVs. The components of CRT TVs that can be disassembled by hand mainly include CRT tubes, plastic shells, printed circuit boards (PCBs), electrical wires, loudspeakers, *etc.*

As an important disassembled part, CRT tubes need to be further separated to funnel glass and panel glass components. The panel glass comprises the front part of the display. The funnel glass is the conical part of the CRT at the rear of the set. So far, the hot-wire method and the diamond cutting method are the dominant methods used to dismantle funnel glass and panel glass. Thereinto, the former is most commonly utilized (85% of licensed plants) (CHEARI, 2015).

PCBAs are printed wiring boards (PWBs) populated with electronic components. Before PCBAs are further treated, the components thereon have to be removed. In this way, PWBs can be used to recover valuable metals. Some of the components can be recycled to extract precious metals, while parts including capacitors and resistors need to be safely disposed as they contain hazardous substances.

2.2.3. CRT glass recycling

The recycling of waste CRT presents a challenge due to the increasing amounts and high lead content (Iniaghe and Adie, 2015). Before 2013, waste CRT glass was mostly used to create new CRTs in China. However, this method has seen no development owing to the introduction of newer, more advanced technologies being used in the manufacture of image displays, such as LCDs. At present,

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