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Review

Electronic waste management approaches: An overview

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ABSTRACT

Electronic waste (e-waste) is one of the fastest-growing pollution problems worldwide given the presence if a variety of toxic substances which can contaminate the environment and threaten human health, if disposal protocols are not meticulously managed. This paper presents an overview of toxic substances present in e-waste, their potential environmental and human health impacts together with management strategies currently being used in certain countries. Several tools including Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA) and Extended Producer Responsibility (EPR) have been developed to manage e-wastes especially in developed countries. The key to success in terms of e-waste management is to develop eco-design devices, properly collect e-waste, recover and recycle material by safe methods, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries, and raise awareness of the impact of e-waste. No single tool is adequate but together they can complement each other to solve this issue. A national scheme such as EPR is a good policy in solving the growing e-waste problems.

1. Introduction

Managing electronic waste (or e-waste) is one of the most rapidly growing pollution problems worldwide. New technologies are rapidly superseding millions of analogue appliances leading to their disposal in prescribed landfills despite potentially their adverse impacts on the environment. The consistent advent of new designs, "smart" functions and technology during the last 20 years is causing the rapid obsolescence of many electronic items. The lifespan of many electronic goods has been substantially shortened due to advancements in electronics, attractive consumer designs and marketing and compatibility issues. For example, the average lifespan of a new computer has decreased from 4.5 years in 1992 to an estimated 2 years in 2005 and is further decreasing (Widmer et al., 2005) resulting in much greater volumes of computers for either disposal or export to developing countries. While difficult to quantify the volume of e-waste generated globally, Bushehri (2010) presented an overview of the volume of e-waste generated in a range of categories in China, Japan and US based on available information for the period 1997–2010 (Table 1). This report estimates that over 130 million computers, monitors and televisions become obsolete annually and that the annual number is growing in the United States (Bushehri, 2010). Around 500 million computers became obsolete between 1997 and 2007 in the United States alone and 610 million computers had been discarded in Japan by the end of December 2010. In China 5 million new computers and 10 million new televisions have been purchased every year since 2003 (Hicks et al., 2005), and around 1.11 million tonnes of e-waste is generated every year, mainly from electrical and electronic manufacturing and production processes, end-of-life of household appliances and information technology products, along with imports from other countries. It is reasonable to assume that a similar generation of e-waste occurs in other countries.

E-waste generation in some developing countries is not such a cause for concern at this stage because of the smaller number and longer half-life of electronic goods in those countries due to financial constraints, on both local community and national scales. The major e-waste problem in developing countries arises from the importation of e-waste and electronic goods from developed countries because it is the older, less ecologically friendly equipment that is discarded from these Western countries 80% of all e-waste in developed countries is being exported (Hicks et al., 2005). Limited safeguards, legislation, policies and enforcement of the safe disposal of imported e-waste and electronic goods have led to serious human and environmental problems in these countries. For instance, e-waste disposal impacts on human health has become a serious issue that has already been noted in case studies from China (Chan et al., 2007; Huo et al., 2007; Qu et al., 2007; Wang et al., 2009b; Xing et al., 2009; Zhao et al., 2008; Zheng et al., 2008).

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Table 1
The quantity of e-waste annually generated in the United States of America, Japan and China.

Countries	Products	Quantity (million)	Classification	Years	References
United States	Computers	500	E-waste	1997–2007	Bushehri (2010)
Japan	Computers	610	E-waste	2010	Bushehri (2010)
China	Computers	5	New products	Every year	Hicks et al. (2005)
	Televisions	10	New products	Since 2003	

Concern arises not just from the large volume of e-waste imported into developing countries but also with the large range of toxic chemicals associated with this e-waste. Numerous researchers have demonstrated that toxic metals and polyhalogenated organics including polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) can be released from e-waste, posing serious risks of harm to humans and the environment (Czuczwa and Hites, 1984; Robinson, 2009; Williams et al., 2008). A review of published reports on e-waste problems in developing countries, and countries in transition, showed that China, Cambodia, India, Indonesia, Pakistan, and Thailand, and African countries such as Nigeria, receive e-waste from developed countries although specific e-waste problems differ considerably between countries. For instance, African countries mainly reuse disposed electronic products whereas Asian countries dismantle those often using unsafe procedures (US Government Accountability Office, 2008; Wong et al., 2007a). Social and human health problems have been recognised in some developing countries and it is worth noting that China, India, and some other Asian countries have recently amended their laws to address the management and disposal of e-waste imports (Widmer et al., 2005). Moreover, some manufacturers of electronic goods have attempted to safely dispose of e-waste with advanced technologies in both developed and developing countries (US Government Accountability Office, 2008; Widmer et al., 2005). Problems associated with e-waste have been challenged by authorities in a number of countries and steps were taken to alleviate them with the introduction of management tools and laws at the national and universal levels. Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Multi Criteria Analysis (MCA) are tools to manage e-waste problems and Extended Producer Responsibility (EPR) is the regulation for e-waste management at the national scale.

This review provides an overview of the risk that e-wastes poses to human and environmental health from recycling and landfill disposals together with tools for the management of such wastes. Human toxicity of hazardous substances in e-waste is based on published case studies from e-waste recycling in China, India and Ghana.

2. Human toxicity of hazardous substances in e-waste

E-waste consists of a large variety of materials (Zhang and Forssberg, 1997), some of which contain a range of toxic substances that can contaminate the environment and threaten human health if not appropriately managed. E-waste disposal methods include landfill and incineration, both of which pose considerable contamination risks. Landfill leachates can potentially transport toxic substances into groundwater whilst combustion in an incinerator can emit toxic gases into the atmosphere. Recycling of e-waste can also distribute hazardous substances into the environment and may affect human health. While there are more than 1000 toxic substances (Puckett and Smith, 2002) associated with e-waste, the more commonly reported substances include: toxic metals (such as barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), lithium (Li), lanthanum (La), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), silver (Ag), hexavalent chromium (Cr(VI)) and persistent organic pollutants (POPs) such as dioxin, brominated flame retardants (BFRs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs), Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and polyvinyl chloride (PVC) (Table 2).

E-waste disposals impact human health in two ways which include: (a) food chain issues: contamination by toxic substances from disposal and primitive recycling processes that result in by-products entering the food chain and thus transferring to humans; and (b) direct impact on workers who labour in primitive recycling areas from their occupational exposure to toxic substances. Along with this, numerous researchers have demonstrated a direct impact of backyard recycling on workers. The danger of e-waste toxicity to human health, both in terms of chronic and acute conditions, has become a serious societal problem and has been well demonstrated by case studies in China (Chan et al., 2007; Huo et al., 2007; Qu et al., 2007; Wang et al., 2009b; Xing et al., 2009; Zhao et al., 2008; Zheng et al., 2008), India (Eguchi et al., 2012; Ha et al., 2009) and Ghana (Asante et al., 2012). For instance, blood, serum, hair, scalp hair, human milk and urine from people who lived in the areas where e-wastes are being recycled showed the presence of significant concentrations of toxic substances. Qu et al. (2007) studied PBDEs exposure of workers in e-waste recycling areas in China and found high levels of PBDEs with the highest concentration of BDE-209 at 3436 ng/g lipid weight in the serum of the sample groups. This is the highest concentration of BDE-209 in humans so far recorded. High levels of Pb (Huo et al., 2007; Zheng et al., 2008) and Cd (Zheng et al., 2008) were found in the blood of children around e-waste recycling regions. Zhao et al. (2008) detected PBBs, PBDEs and PCBs in hair samples at 57.77, 29.64 and 181.99 ng/g dry weight, respectively which were higher than those from reference sites. Wang et al. (2009b) found Cu (39.8 μg/g) and Pb (49.5 μg/g) in scalp hair samples. PCDD/Fs (Chan et al., 2007) and PCBs (Xing et al., 2009) were detected in human milk samples at 21.02 pg/g and 9.50 ng/g, respectively. In India concentrations of Cu, Sb and Bi in the hair of e-waste recycling workers was higher than at the reference site (Ha et al., 2009) and levels of tri to tetra-chlorinated PCBs, tri to tetra-chlorinated OH-PCBs, PBDEs, octa-brominated OH-PBDEs, and tetra-BPhs in the serum of workers from e-waste recycling areas were higher than those in serum taken from people living near the coastal area (Eguchi et al., 2012). Moreover, in Ghana significant concentrations of Fe, Sb and Pb in the urine of workers from primitive recycling sites were found at 130, 0.89 and 6.06 μg/l, respectively. These were higher than at reference sites (Asante et al., 2012). These findings confirm that human exposure to heavy metals and POPs released from e-waste treatment processes pose significant health risk to workers and local inhabitants especially women and children. Also these studies demonstrate the effect of long-term exposure to human. Similar studies need to be extended to other developing countries or countries in transition where back yard e-waste recycling is being conducted. Although, the Stockholm Convention (UNEP, 2012) takes action to reduce and prevent global contamination from POPs, there has been significant delay with the implementation of guidance and legislation in some countries. For