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RECYCLING E-WASTE

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Abstract-- "E-waste" is a popular, informal name for electronic products nearing the end of their "useful life. "E-wastes are considered dangerous, as certain components of some electronic products contain materials that are hazardous, depending on their condition and density. The hazardous content of these materials pose a threat to human health and environment. Discarded computers, televisions, VCRs, stereos, copiers, fax machines, electric lamps, cell phones, audio equipment and batteries if improperly disposed can leach lead and other substances into soil and groundwater. Many of these products can be reused, refurbished, or recycled in an environmentally sound manner so that they are less harmful to the ecosystem. This paper highlights the hazards of e-wastes, the need for its appropriate management and options that can be implemented.

INTRODUCTION

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.

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. 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 2003million 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.

EFFECTS ON ENVIRONMENT AND HUMAN HEALTH

Disposal of e-wastes is a particular problem faced in many regions across the globe. Computer wastes that are land filled produces contaminated leachates which eventually pollute the groundwater. Acids and sludge obtained from melting computer chips, if disposed on the ground causes acidification of soil. For example, Guiyu, Hong Kong a thriving area of illegal e-waste recycling is facing acute water shortages due to the contamination of water resources.

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This is due to disposal of recycling wastes such as acids, sludges etc. in rivers. Now water is being transported from faraway towns to cater to the demands of the population. Incineration of e-wastes can emit toxic fumes and gases, thereby polluting the surrounding air. Improperly monitored landfills can cause environmental hazards. Mercury will leach when certain electronic devices, such as circuit breakers are destroyed. The same is true for polychlorinated biphenyls (PCBs) from condensers. When brominated flame retardant plastic or cadmium containing plastics are landfilled, both polybrominated dlphenyl ethers (PBDE) and cadmium may leach into the soil and groundwater. It has been found that significant amounts of lead ion are dissolved from broken lead containing glass, such as the cone glass of cathode ray tubes, gets mixed with acid waters and are a common occurrence in landfills.
Not only does the leaching of mercury poses specific problems, the vaporization of metallic mercury and dimethylene mercury, both part of Waste Electrical and Electronic Equipment (WEEE) is also of concern. In addition, uncontrolled fires may arise at landfills and this could be a frequent occurrence in many countries.

When exposed to fire, metals and other chemical substances, such as the extremely toxic dioxins and furans (TCDD tetrachlorodibenzodioxin, PCDDs-polychlorinated dibenzodioxins. PBDDs-polybrominateddibenzo-dioxin and PCDFs poly chlorinated dibenzo furans) from halogenated flame retardant products and PCB containing condensers can be emitted. The most dangerous form of burning e-waste is the open-air burning of plastics in order to recover copper and other metals. The toxic fall-out from open air burning affects both the local environment and broader global air currents, depositing highly toxic by products in many places throughout the world.

Source of e-wastes	Constituent	Health effects
Solder in printed circuit boards, glass panels and gaskets in computer monitors	Lead (PB)	✓ Damage to central and peripheral nervous systems, blood systems and kidney damage. ✓ Affects brain development of children.
Chip resistors and semiconductors	Cadmium (CD)	✓ Toxic irreversible effects on human health. ✓ Accumulates in kidney and liver. ✓ Causes neural damage. ✓ Teratogenic.
Relays and switches, printed circuit boards	Mercury (Hg)	✓ Chronic damage to the brain. ✓ Respiratory and skin disorders due to bioaccumulation in fishes.
Corrosion protection of untreated and galvanized steel plates, decorator or hardner for steel housings	Hexavalent chromium (Cr) VI	✓ Asthmatic bronchitis. ✓ DNA damage.
Cabling and computer housing	Plastics including PVC	Burning produces dioxin. It causes ✓ Reproductive and developmental problems; ✓ Immune system damage; ✓ Interfere with regulatory hormones
Plastic housing of electronic equipments and circuit boards.	Brominated flame retardants (BFR)	✓ Disrupts endocrine system functions
Front panel of CRTs	Barium (Ba)	Short term exposure causes: ✓ Muscle weakness; ✓ Damage to heart, liver and spleen.
Motherboard	Beryllium (Be)	✓ Carcinogenic (lung cancer) ✓ Inhalation of fumes and dust. Causes chronic beryllium disease or beryllicosis. ✓ Skin diseases such as warts.

Above Table summarizes the health effects of certain constituents in e-wastes. If these electronic items are discarded with other household garbage, the toxics pose a threat to both health and vital components of the ecosystem. In view of the ill-effects of hazardous wastes to both environment and health, several countries exhorted the need for a global agreement to address the problems and challenges posed by hazardous waste. Also, in the late 1980s, a tightening of environmental regulations in industrialized countries led to a dramatic rise in the cost of hazardous waste disposal. Searching for cheaper ways to get rid of the wastes, "toxic traders" began shipping hazardous waste to developing countries. International outrage following these irresponsible activities led to the drafting and adoption of strategic plans and regulations at the Basel Convention. The Convention secretariat, in Geneva, Switzerland, facilitates and implementation of the Convention and related agreements. It also provides assistance and guidelines on legal and technical issues, gathers statistical data, and conducts training on the proper management of hazardous waste.

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Environmental Impacts of E-Waste during Treatment Processes

The presence of toxic substances in e-waste was recognised only within the last 20 years. There is inadequate legislation worldwide for effective management of such waste. The rapid growth of e-waste and the ineffectiveness of legislation has led to inappropriate management strategies in both developed and developing countries, leading to profound impacts on the environment. Management of e-waste by recycling and by disposal to landfills has been shown to pose significant risks to the environment

Recycling

It is estimated that 75% of electronic items are stored due to uncertainty of how to manage it. These electronic junks lie unattended in houses, offices, warehouses etc. and normally mixed with household wastes, which are finally disposed off at landfills. This necessitates implementable management measures.

In industries management of e-waste should begin at the point of generation. This can be done by waste minimization techniques and by sustainable product design. Waste minimization in industries involves adopting:

- ✓ *inventory management,*
- ✓ *production-process modification,*
- ✓ *volume reduction,*
- ✓ *Recovery and reuse.*

Vast quantities of e-waste are now being moved around the world for recycling in developing countries using manual processes in backyards of residential properties, resulting in significant contamination of soil, water and air in these countries. Such practices have also resulted in the poisoning of many local people engaged with the recycling process. For example, Guiyu and Taizhou in China, Gauteng in South Africa, New Delhi in India, Accra in Ghana and Karachi in Pakistan are the large e-waste recycling sites and this is where extensive pollution is emitted from the e-waste recycling processes (Asante et al., 2012, Brigden et al., 2005, Puckett and Smith, 2002, Tsydenova and Bengtsson, 2011, Widmer and Lombard, 2005 and Widmer et al., 2005). The investigations from Guiyu, China showed POPs and heavy metals in air, dust, soil, sediment, and freshwater around the e-waste recycling site (Chen et al., 2009, Deng et al., 2007, Leung et al., 2010 and Wang et al., 2009a). The major heavy metals released included Pb, Cd, Ni, Cr, Hg and As. Organic pollutants emitted included PAHs, PCBs, brominated flame retardants (BFRs) such as PBDEs, and polychlorinated dibenzo-p-dioxin/furans (PCDD/Fs), which can be formed during crude thermal processes of e-waste recycling. Polybrominateddibenzo-pdioxin/furans (PBDD/Fs) may occur as impurities in PBDEs, by-products of PBDE degradation during production, weathering, and recycling of flame-retardant plastics. It is apparent from these studies that the entire ecosystem including soil, sediment, water and air is being contaminated by these toxic substances . A wide range in the concentrations of total PBDEs, PAHs, PCDD/Fs and PCBs have been reported in surface soils from e-waste recycling sites. For instance PBDE ranged from 0.26 to 4250 ng/g (dry weight) (Cai and Jiang, 2006, Leung et al., 2007, Wang et al., 2005 and Wang et al., 2011), PAHs from 44.8 to 20,000 ng/g (dry weigh) (Leung et al., 2006, Shen et al., 2009, Tang et al., 2010 and Yu et al., 2006), PCDD/Fs from 0.21 to 89.80 ng/g (Leung et al., 2007 and Shen et al., 2009) and PCBs from 11 to 5789.5 ng/g (Shen et al., 2009 and Tang et al., 2010), in Guiyu and Taizhou, China. In Bangalore, India high concentrations of Ag, Bi, Cd, Cu, In, Hg, Pb, Sn and Zn were found in soil near recycling areas (Ha et al., 2009). On the impact of e-waste on water, Wang and Guo (2006) found appreciable concentrations of Pb in surface water downstream of the recycling industry in Guiyu. The concentration of Pb was as high as 0.4 mg/l which is eight times higher than the drinking water standard in China ($\leqslant$0.05 mg/l). Wong et al. (2007b) reported the presence of elevated levels of toxic metals in Liangjian and Nanya Rivers compared to that in the reservoir outside of Guiyu. They found that the rivers inside Guiyu had higher dissolved metal concentrations than those sampled outside. Therefore, recycling activities in Guiyu can be shown to adversely impact water quality surrounding this area (Wang and Guo, 2006). On air quality, given that most e-waste disposal and recycling has been in China and other developing countries, most of the studies are from these regions with reports demonstrating major impacts of backyard e-waste disposal and recycling. Results from these studies demonstrate severe contamination of the ambient air from chlorinated and brominated compounds and heavy metals around e-waste recycling sites in China. High concentrations of heavy metals including Cr, Zn and Cu were detected at 1161, 1038 and 483 ng/m3, respectively which were 4–33 times higher than those in other Asian countries and PAHs contained in TSP and PM2.5 were found at 40–347 and 22.7–263 ng/m3, respectively (Deng et al., 2006). PBDEs associated with TSP and PM2.5 were detected at 124 and 62.1 μg/m3, respectively while the high pollution levels of PBDEs in Guiyu were 58–691 times higher than at other urban sites (Deng et al., 2007). The concentrations of PBDD/Fs were found to be at 8.12–61 pg/m3. Moreover, PCDD/Fs in Guiyu were detected at 64.9–2365 pg/m3 and these are the highest concentrations in ambient air worldwide (Li et al., 2007). Early reports implied that the air pollution in Guiyu has also been traced to e-waste recycling plants. In Bangalore, India high levels of Bi, Co, Cr, Cu, In, Mn, Pb, Sb, Sn and Tl were found in air around recycling areas which were higher than the levels around reference sites (Ha et al., 2009). In addition, in Thailand the level of ∑PBDEs (BDE-17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) in the indoor air of an e-waste storage facility were found at 46–350 pg/m3 whereas in outdoor locations, air pollutants were found at 8–150 pg/m3 which were lower than the levels of PBDEs in China (Muenhor et al., 2010).

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Material Flow Analysis (MFA)

Before the Basel Convention came into force large volumes of e-waste from developed countries were exported for reuse or recycling in developing countries especially China, India and South Africa. MFA is a tool used to study the route of material (e-waste) flowing into recycling sites, or disposal areas and stocks of materials, in space and time. It links sources, pathways, and the intermediate and final destinations of the material. Material Flow Analysis is a decision support tool for environmental and waste management (Brunner and Rechberger, 2004). This tool can be applied to develop appropriate e-waste management. This includes a consideration of the flow of e-waste and its assessment it in terms of environmental, economic and social values. Shinkuma and Nguyen Thi Minh (2009) used MFA to investigate the flow of e-waste in Asia. They found that secondhand electronic devices from Japan are reused in Southeast Asia (e.g., Vietnam and Cambodia) while most of the e-waste is recycled in Gangdong Province, China, where improper recycling methods were being used. In addition, Yoshida et al. (2009) found that the proportion of personal computers sent for domestic disposal and recycling decreased to 37% in fiscal year 2004, while the proportion of domestic reuse and exports increased to 37% and 26%, respectively in Japan. Liu et al., 2006a, Jain and Sareen, 2006 and Osibanjo and Nnorom, 2008 and Steubing et al. (2010) investigated e-waste generation using MFA. Many different methods are being used to estimate possible quantities of e-waste. Liu et al. (2006a) and Jain and Sareen (2006) used market supply method which provided data for production and sales in regions, and time for estimation. Steubing et al. (2010) also used the market supply and survey method to estimate e-waste generation. Osibanjo and Nnorom (2008) used surveys to estimate quantities of e-waste. They found that e-waste generation will increase in China, India, Nigeria and Chile. For instance, based on MFA, it was reported that the quantiy of e-waste would double from 2005 to 2010 and increase by 70% for obsolete devices by 2020 in China (Liu et al., 2006b), while it will increase four to five times during 2010–2019 in Chile (Steubing et al., 2010). Streicher-Porte (2007) used MFA and evaluation of economic values as a tool for system analysis of the Au and Cu that flows from personal computer recycling in India. They found that the concentration of Au and Cu and the high value of these metals resulted in profits for recyclers. It is apparent from the study conducted by Streicher-Porte (2007) that coupling of MFA and economic evaluation can be a useful tool when limited data is available and where there is rapid economic growth.

Responsibilities of the Government

(i) Governments should set up regulatory agencies in each district, which are vested with the responsibility of co-ordinating and consolidating the regulatory functions of the various government authorities regarding hazardous substances.

(ii) Governments should be responsible for providing an adequate system of laws, controls and administrative procedures for hazardous waste management (Third World Network. 1991). Existing laws concerning e-waste disposal be reviewed and revamped. A comprehensive law that provides e-waste regulation and management and proper disposal of hazardous wastes is required. Such a law should empower the agency to control, supervise and regulate the relevant activities of government departments.

Under this law, the agency concerned should

- ✓ *Collect basic information on the materials from manufacturers, processors and importers and to maintain an inventory of these materials. The information should include toxicity and potential harmful effects.*
- ✓ *Identify potentially harmful substances and require the industry to test them for adverse health and environmental effects.*
- ✓ *Control risks from manufacture, processing, distribution, use and disposal of electronic wastes.*
- ✓ *Encourage beneficial reuse of "e-waste" and encouraging business activities that use waste". Set up programs so as to promote recycling among citizens and businesses.*
- ✓ *Educate e-waste generators on reuse/recycling options*

(iii) Governments must encourage research into the development and standard of hazardous waste management, environmental monitoring and the regulation of hazardous waste-disposal.

(iv)Governments should enforce strict regulations against dumping e-waste in the country by outsiders. Where the laws are flouted, stringent penalties must be imposed. In particular, custodial sentences should be preferred to paltry fines, which these outsiders / foreign nationals can pay.

(v) Governments should enforce strict regulations and heavy fines levied on industries, which do not practice waste prevention and recovery in the production facilities.

(vi) Polluter pays principle and extended producer responsibility should be adopted.

(vii) Governments should encourage and support NGOs and other organizations to involve actively in solving the nation's e-waste problems.

(viii) Uncontrolled dumping is an unsatisfactory method for disposal of hazardous waste and should be phased out.

(viii) Governments should explore opportunities to partner with manufacturers and retailers to provide recycling services.

Responsibilities of the Citizen

Waste prevention is perhaps more preferred to any other waste management option including recycling. Donating electronics for reuse extends the lives of valuable products and keeps them out of the waste management system for a longer time. But care should be taken while donating such items i.e. the items should be in working condition.

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Reuse, in addition to being an environmentally preferable alternative, also benefits society. By donating used electronics, schools, non-profit organizations, and lower-income families can afford to use equipment that they otherwise could not afford. E-wastes should never be disposed with garbage and other household wastes. This should be segregated at the site and sold or donated to various organizations.

While buying electronic products opt for those that:

- ✓ *are made with fewer toxic constituents*
- ✓ *use recycled content*
- ✓ *are energy efficient*
- ✓ *are designed for easy upgrading or disassembly*
- ✓ *utilize minimal packaging*
- ✓ *offer leasing or take back options*
- ✓ *Have been certified by regulatory authorities. Customer's should opt for upgrading their computers or other electronic items to the latest versions rather than buying new equipments.*

CONCLUSION

E-waste is a serious problem at both local and global scales. E-waste problems appeared initially in developed countries and now extend widely to other countries around the world. The volume of e-waste is growing fast because consumer technology is rapidly changing and the innovation of technology results in rapid obsolescence, thus generating massive amounts of e-waste. E-waste consists of many different materials, some of which contain a variety of toxic substances that can contaminate the environment and threaten human health, if the end-of-life management is not meticulously managed. Many case study from e-waste recycling plants confirmed that the toxic chemicals such as heavy metals and POPs have and continue to contaminate the surrounding environment. This results in considerable accumulation of hazardous substances into the ecosystem and which can adversely impact human health. Both laboratory simulation studies and landfill leachates from disposal sites demonstrate the release of toxic substances from e-wastes with the concentration varying significantly between field and laboratory based studies.

In order to mitigate e-waste problems, there are investigations in term of the volume, nature and potential environmental and human health impacts of e-waste and extensive research into e-waste management. Several tools including LCA, MFA, MCA and EPR approach for e-waste management could ultimately ameliorate most e-waste problems. Any one tool may be imperfect but in concert they can complement each other to solve this issue. Moreover, a national scheme such as EPR is a good policy tool to solve the growing e-waste problem. Interaction of four tools can drive to success for e-waste management that is to develop eco-designed devices, to 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, to raise awareness of the impact of e-waste pollution of both users and manufacturers. Over and above all of these, no matter how well the policies are introduced and implemented benefits will only arise provided end users are prepared to accept introduced policies and adhere to them.

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