Achieving sustainability in solving the electronic waste (e-waste) problem

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Abstract

Waste from used electrical and electronic equipment, commonly known as e-waste, is growing at a higher rate than the regular municipal waste streams. Global generation of e-waste in 2019 was 53.6 million tonnes. Rising demand for high technology products and their early obsolescence coupled with lack of proper end-of-life management options have all led to unsustainable management of e-waste in many countries. Recycling, design for environment, extended producer responsibility and public-private partnerships (PPPs) are some of the practices attempted by many countries to achieve sustainability in solving the e-waste problem. This paper provides an overview of the practices mentioned above.

Key Words: *Design for environment, E-waste, Extended producer responsibility, Health impacts, Public-private-partnerships, Sustainability*

Introduction

The waste from electrical and electronic equipment (EEE), commonly referred to as e-waste or WEEE, is growing fast in the world with a generation of 53.6 million tonnes in 2019 and projected to grow to 74.7 million tonnes by 2030 (Forti *et al.*, 2020). The modern world heavily depends on EEE to drive the high technology sector, critical for many countries' economic development. The benefits of the high technology sector are well known. However, the environmental and health impacts of poor management of end-of-life EEE are relatively unknown. The issue is compounded by the fact that the average life span of many EEEs is reducing by the day due to the availability of products with increased memory, processing power, and attractive design features. This has led to the early obsolescence of many EEEs, causing a significant increase in e-waste generation. Many countries are grappling with the options to manage this challenging waste stream, which consists of several toxic compounds and valuable ones. This paper aims to provide an overview of some initiatives attempted by many countries to move towards proper management of e-waste.

Electronic and electrical industry and generation of e-waste

E-waste comprises many EEE and its accessories used EEE with an electronic circuit or EEE which utilises electrical power or battery power. Table 1 describes some of the commonly used items. The determination of correct data related to e-waste generation in a particular country is a difficult task. This is because some of the used EEEs do not enter the end-of-life management processes as they are stored by the households. Therefore, most estimates are based on manufacturing or sales data or by estimating the products' lifespan. One of the most recent and comprehensive analyses and estimation of e-waste generated around the world was conducted by Forti *et al.* (2020). According to this study, the global total e-waste generation in 2019 was 53.6 million metric tonnes (Mt). The Asian region generated the most substantial quantity of e-waste (24.9 Mt), followed by the American region (13.1 Mt), Europe region (12 Mt), Africa (2.9 Mt), and Oceania (0.7 Mt). Furthermore, Forti *et al.* (2020) has estimated that within the Asian region, China generated the largest amount of e-waste (10.1 Mt), followed by India (3.2 Mt) and Japan (2.5 Mt). Table 2 summaries the e-waste generated in selected countries around the world. In general, EEE comprises different metals and chemical compounds, many of which are toxic to human health and the environment.

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Table 1. Classification of e-waste

Category	Items
Thermal products	Refrigerators, air conditioners, freezers
Monitors and Screens	Televisions, laptops, notebooks, monitors, tablets
Lamps	Light bulbs, fluorescent bulbs,
Heavy items	Washing machines, dryers, dishwashing machines, PV panels, photocopiers, electric stoves
Small items	Microwaves, electric kettles, video cameras, calculators, toys, electrical tools, small medical devices, toasters, shavers, hairdryers, scales, many small electrical and electronic items used in the kitchen
Small high technology equipment	Mobile phones, personal computers, printers, telephones, routers

Table 2. E-waste in selected countries

Country	E-waste (tonnes/year)	E-waste (kg/person)
Argentina	465,000	10.3
Australia	554,000	21.7
Brazil	2,143,000	10.2
Canada	757,000	20.2
China	10,129,000	7.2
Hong Kong	153,000	20.2
France	1,362,000	21.0
Germany	1,607,000	19.4
India	3,230,000	2.4
Indonesia	1,618,000	6.1
Japan	2,569,000	20.4
Nigeria	461,000	2.3
Republic of Korea	818,000	15.8
Russian Federation	1,631,000	11.3
Saudi Arabia	595,000	17.6
Singapore	113,000	19.9
United Kingdom	1,598,000	23.9
United States of America	6,918,000	21.0

When these toxic materials are intact with the EEE, they do not cause harm to humans or the environment. However, when EEE is dismantled during their end-of-life processes such as recycling, these compounds become exposed to the environment. Poor recycling practices adopted by many countries result in severe human health and environmental impacts. Generally, EEE contains toxic metals such as (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), which are also known as flame retardants.

Although in 2003, the European Union banned the manufacturing of EEE containing these toxic metal and compound through their Restrictions of Hazardous Substances (RoHS) Directive, there is a considerable backlog of used and old EEE in homes and offices awaiting disposal. The environmental sound management (ESM) of e-waste has also become a significant challenge to many countries due to the widespread transboundary movement of used EEE in the name of recycling or final disposal. A significant amount of e-waste and used EEE are transferred from industrialised countries to

developing countries for end-of-life processes. Unfortunately, most e-waste processing facilities in developing countries do not have the technical skills to operate in an environmentally sound manner due to the heavy involvement of the informal waste recycling sector. Poor extraction of metals, open burning, and other rudimentary practices are causing significant impacts on human health and the environment.

Human health and environmental impacts of e-waste recycling

The human health and environmental impacts of e-waste recycling have been well studied by researchers around the world, in particular, in countries where e-waste recycling is predominantly undertaken by the informal sector. This section describes some of these studies conducted to highlight the human impacts and environmental effects caused by informal e-waste recycling. Ackah *et al.* (2019) studied the effects of trace elements in e-waste on the topsoil and subsoil of e-waste recycling sites in Accra, Ghana. They found metal concentrations in Agbogbloshie site (one of the largest informal e-waste recycling sites in the world) exceeded the Dutch Soil Intervention values by 72% (Cu), 57% (Zn), 57% (Pb), 38% (Ba), 16%

(Cd) and 2% (As) meaning significant metal contamination in the site. They also found substantial Pb contamination in open burning and dismantling areas of the site, causing significant carcinogenic risks to people living nearby. A similar study conducted at a major e-waste dumpsite in Lagos, Nigeria (Alabi *et al.*, 2020) found an increase in Pb blood levels of teenage scavenging the site with a range from 2.84 to 189.44 µg/L compared to the control group range 0.01 to 4.21 µg/L. A study conducted by Alam *et al.* (2019) to assess the genotoxicity of e-waste leachates at an e-waste dumpsite in Metro Manila, Philippines showed the heavy presence of Cd, Cu, Ni, Pb and Zn in the soil samples of the e-waste recycling sites and the hair of the informal recyclers. Cai *et al.* (2019) investigated the effect of lead exposure on child sensory integration by correlating the blood levels of children with sensory processing measures living close to e-waste recycling town in China (Guiyu). They concluded that Pb exposure in e-waste recycling areas might impact the serum cortisol levels and an increase in the difficulty of child sensory integrations, further confirming the impacts on humans, especially young children. Tables 3, 4, and 5 summarises selected studies conducted on the effects of e-waste recycling on human health and the environment.

Table 3. Selected studies on impacts on sediments around recycling sites

Contaminants and study area	Reference
Investigation of polycyclic aromatic hydrocarbons (PAHs) in soil near an informal e-waste facility in China	Gu <i>et al.</i> , 2019
Study into soil pollution caused by metals from e-waste recycling activities Pearl River Delta	He <i>et al.</i> , 2017
Contamination of soils by PAHs near informal e-waste recycling area in Vietnam	Hoa <i>et al.</i> , 2020
Distribution of heavy metals in the soils near an informal e-waste recycling facility in Nigeria	Isimekhai <i>et al.</i> , 2017
Contamination of soil by heavy metals generated from a Nigerian e-waste site	Jiang <i>et al.</i> , 2019
Changes in the microbe structure in sediments from rivers near e-waste recycling facilities in China	Liu <i>et al.</i> , 2018
Determination of PBDEs in soils and river sediments near an e-waste recycling facility in Vietnam	Matsukami <i>et al.</i> , 2017
Study into impact from PAHs, PBDEs, and PCBs on the sediments near e-waste recycling site in Ghana	Moeckel <i>et al.</i> , 2020
Impact of chlorobenzenes and PCBs in soils from an e-waste recycling area in Vietnam	Nishimura <i>et al.</i> , 2018
Investigation of chlorinated and brominated PAHs in soils resulting from open burning of e-waste	Nishimura <i>et al.</i> , 2017

Table 4. Selected studies on human health impacts

Human health impacts and the study area	Reference
Impact of health on people living near e-waste recycling activities at Agbogbloshie dumpsite, Ghana	Adusi <i>et al.</i> , 2020
Health impacts due to organic compounds from e-waste recycling in developing countries	Awere <i>et al.</i> , 2020
Exposure through inhalation of particulate matter due to open burning of e-waste in Thailand	Bungadaeng <i>et al.</i> , 2019
Human health and injuries among e-waste recycling workers in Ghana	Burns <i>et al.</i> , 2019
Generation of dioxin-like compounds in e-waste recycling areas	Dai <i>et al.</i> , 2020
Study into the association between open burning of e-waste and childhood lymphoma in the West Bank, Palestine	Davis and Garb, 2019
Determination of mercury levels in the urine of workers in e-waste shops in Thailand	Decharat , 2018
Generation and exposure of PBDEs in a modern e-waste dismantling facility in China	Die <i>et al.</i> , 2019
Study into human health impacts from air pollution resulting from open burning of e-waste in India	Gangwar <i>et al.</i> , 2019
Disruption of thyroid hormone-regulated proteins in residents living near an e-waste recycling site from PAHs, and PBDEs	Guo <i>et al.</i> , 2019
The correlation of maternal urinary metabolites of PAHs and adverse birth outcomes of people living near an e-waste recycling area	Huo <i>et al.</i> , 2019
Concentration of heavy metals in pregnant women and new born children resulting from informal e-waste recycling in China	Kim <i>et al.</i> , 2019
Impacts of birth outcomes connected with maternal exposure of heavy metals from informal e-waste recycling in China	Kim <i>et al.</i> , 2020

Table 5. Studies on impacts on biota.

Impacts on biota and the study area	Reference
Study in polychlorinated biphenyls in settled dust from informal e-waste recycling in India	Chakraborty <i>et al.</i> , 2016
Concentration of flame retardants and organophosphate esters in the environment near e-waste recycling facilities	Gravel <i>et al.</i> , 2019
Determination of chlorinated paraffins in aquatic organisms near an e-waste site	Guan <i>et al.</i> , 2020
Environmental impacts and human exposure to flame retardants from e-waste recycling in Pakistan	Iqbal <i>et al.</i> , 2017
Determination of PCBs near an e-waste recycling facility in North-Rhine Westphalia	Klees <i>et al.</i> , 2017

Formal e-waste recycling

Recycling is widely recognised as one of the most popular options for end-of-life management of e-waste. Many countries are starting to realise that although e-waste contains many toxic metals and chemical compounds, they also provide valuable metals that have value in the secondary resource market. This has resulted in many industrialised countries investing funds to develop formal e-waste recycling facilities adopting advanced technologies. Unfortunately, even with such formal facilities, many industrialised countries have achieved a low recycling rate for many reasons. The challenge for

e-waste recycling enterprises is to gain access to e-waste for processing. Many households tend to store their used EEE at home, hoping that they will increase value in the future. Due to this fact, many used EEEs are not entering formal e-waste recycling paths. Another issue is most of the e-waste collected by recycling companies in developed countries finally end up in recycling facilities in developing countries. In comparison to industrialised countries, e-waste recycling in developing and emerging economies is predominantly undertaken by the informal sector. However, lately, there has been some movement of

formal e-waste recycling facilities in these regions. The formal e-waste recycling facilities in developing and emerging economies encounter stiff competition for e-waste from the well-established informal e-waste processors.

Formal e-waste recycling - Example 1

E-Parisaraa Pvt. Ltd (<http://ewasteindia.com/>)

The company aims to reduce the e-waste being disposed of in landfills or partly recycled by the informal sector that has poor operational processes. E-Parisaraa has the objective of converting e-waste into beneficial resources using environmentally friendly, locally appropriate technologies. These processes are capable of dismantling toner cartridges, recovery of gold from printed circuit boards, recovery of silver from silver-coated components, and shredding printed circuit boards for further processing in Umicore precious metal refining company in Belgium.

Formal e-waste recycling – Example 2

Terrapro (<http://terrapro.in/>)

Terrapro was set up as the first PRO to provide services for the manufacturers of EEE to take responsibility for their end-of-life products. According to the E-waste Management Rules 2016 in India, the manufacturers must fulfill several obligations under the EPR scheme. Terrapro provides a total solution to the manufacturers by assisting them with plans to achieve specific goals required under the regulations and the preparation of EPR reporting paperwork.

Formal e-waste recycling - Example 3

Attero Recycling (<http://www.attero.in/>)

Attero is a metal extraction and e-waste refurbishing facility in India with establishments in several cities. E-waste to the company mainly comes from the informal waste recycling sector and major manufacturers. The company takes away the printed circuit boards from the informal waste collectors by providing a higher price, thereby avoiding the potential environmental and health benefits. The company has developed a comprehensive e-commerce platform to facilitate the sale of refurbished electronics to customers.

Design for Environment (DfE)

Design for Environment (DfE), commonly referred to as Eco-design, investigates the entire life cycle of a project (from raw material extraction to final disposal) to determine the environmental impacts at each stage and propose changes to product design to minimise those impacts. Such a process involves designing products for practices such as design for energy efficiency, design for re-use, re-manufacture, disassembly and recycling, and design for resource conservation. The rationale behind adopting DfE is due to the fact that environmental impacts from products are continually rising, and 60-80% of its environmental impacts are determined during the design phase. Given the challenges of environmentally sound recycling of e-waste, it is crucial to adopt DfE practices to move away from end-of-pipe considerations. Towards this, the substitution of toxic raw materials with non-toxic materials, designing EEE for easy disassembly and repair, and designing EEE for energy efficiency to reduce the power consumption could contribute significantly to reduce the environmental footprint of the high technology industry. For example, the industry is now required by many countries to remove Pb metal from the manufacturing process. Pb was highly utilised in the soldering process of electronic circuits. The industry has now moved to lead-free soldering.

DfE – Example

Dell is a multinational company that manufactures computers and related products. Their DfE program is one of the most comprehensive among computer manufacturers. Dell's system incorporates DfE at four different stages: Design and Build, Shipping, Use, and Re-use/recycling. During the design and build stage, Dell ensures that the substances they use for their products do not cause any harm to the environment and human health. For example, Dell has phased out medium chained chlorinated paraffins, certain phthalates, and polycyclic aromatic hydrocarbons in addition to the substances banned under the European Union's Restriction of Hazardous Substances Directive (RoHS). During the shipping stage, Dell ensures the use of sustainable packaging materials, smaller transportation footprints, and the use of recyclable materials.

Extended Producer Responsibility (EPR)

The Extended Producer Responsibility (EPR) involves making the producer or importer of a product physically and financially responsible for collection and processing of their products after use. The rationale behind EPR is shifting the administrative, logistical, and financial responsibility from government authorities to the manufacturers or importers of the products. Through this process, it is also expected that manufacturers will take into account the environmental considerations (design for the environment) in their manufacturing process to minimise the end-of-life processing costs. EPR has been implemented in many industrialised countries with great success in dealing with the e-waste problem. The reason for this success is the ability of these countries to keep clear records of original manufacturers or importers. Identifying the manufacturer or importer is a crucial element of a successful EPR system. However, the same cannot be said when it comes to emerging and developing nations. Some of these countries already have EPR systems to deal with the e-waste problem; however, successful implementation has become a major challenge for various reasons. The European Union implemented an EPR system in 2003 to deal with the e-waste problem through its Waste Electrical and Electrical Directive (WEEE Directive). Since then, many countries adopted various forms of EPR, including product take-back schemes, advanced recycling fees, container deposit schemes, etc. Most of these schemes are managed by Producer Responsibility Organisations (PROs), typically appointed by the government to administer the system on their behalf. The manufacturers or importers of EEE pay an annual fee to the PRO-based on their market input. The fee is utilised by the PRO towards the logistics and proper recycling of e-waste through licensed recyclers.

EPR – Example 1

Samsung Takeback and Recycling

(<https://www.samsung.com/us/aboutsamsung/sustainability/environment/responsible-recycling/>)

The Samsung takeback and recycling program (STAR) provides free drop-off of Samsung branded products in several locations in Indian cities. They provide fixed drop-off locations for smaller

products, such as mobile phones and cameras. For larger items such as televisions, washing machines, and refrigerators, Samsung offers free pick-up service from the customers. The STAR initiative also includes a program to raise awareness among the consumers about the proper recycling of used EEEs.

EPR – Example 2

Xiaomi (India) (<https://karosambhav.com/>)

Xiaomi, one of the largest selling mobile phones and smart television brands in India, has developed a nationwide campaign to manage e-waste responsibly. The company has an extensive home pick up service to collect their used products from Indian homes. To expand their services, Xiaomi has partnered with Karo Sambhav, a leading PRO appointed by the Indian government. The customers can also utilise the collection points provided by Karo Sambhav to deposit their used Xiaomi brand products.

Public-private partnerships (PPPs) to manage e-waste

The public-private partnerships, commonly known as PPPs, form a crucial link in the e-waste management system. While the national governments set the agenda or targets to achieve in solving the e-waste problem, the operational responsibility of the system heavily depends upon the financial and human resource potential of the provincial or the municipal sector. These alone are unable to achieve sound e-waste management systems, thus requiring input from the private sector to build the necessary infrastructure and bring in the technology. The PPPs also benefit the businesses and the community as they can effectively utilise the services provided by the private sector. The private sector can also benefit from expanding its marketing potential and enhancing their productivity.

PPP - Example 1

Clean e-India Initiative

(<http://www.cleaneindia.org/>)

The Clean e-India initiative was launched by Attero, which is one of the largest e-waste recycling companies in India. The initiative was implemented to ensure responsible and sustainable collection and recycling of e-waste across the nation. The program

utilises a services of e-captains who come and visit the households to collect their e-waste from the doorstep. The e-captain transfers the products to the Attero e-waste processing center for responsible recycling.

PPP – Example 2

E-waste: From Toxic to Green (<https://www.chintan-india.org/>)

As in many developing countries, informal e-waste recycling sector is very active in India. Although the collection and recycling rate is high, these groups are not aware of the environmental and human health impacts of their operation. To address this issue, the Toxic to Green initiative was launched to train the waste pickers for safe disposal and recycling of e-waste. Chintan, an Indian non-governmental organisation, has cooperated with the government sector to develop a partnership with a registered association of waste pickers, to train their members on how to collect and handle e-waste in a safe manner.

Conclusion

E-waste has become a hidden dilemma as it is growing at a faster rate than many other waste streams but with low visibility. The paper highlighted the lack of proper formal infrastructure to process end-of-life EEE, inability to deal with e-waste processing conducted by the informal e-wastesector, weak regulatory framework to deal with this emerging waste stream, underdeveloped/poor waste management systems, illegal import of e-waste for recycling, accessing funds towards developing proper e-waste recycling facilities, awareness-raising among the consumers, and effective implementation of EPR systems as key driving challenges for moving towards a sustainable e-waste management system. The paper also found that the private sector can bring in the technology and investment to assist the public sector in dealing with the e-waste problem. However, it would be difficult to attract the private sector towards e-waste management unless the policymakers have created the enabling conditions to ensure they receive economic and business benefits from the processing of e-waste.

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