Chapter 4

The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste

Daniel Mmereki, Baizhan Li, Andrew Baldwin and Liu Hong

Additional information is available at the end of the chapter

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Abstract

The problem of e-waste has forced governments of many countries to develop and implement environmentally sound management practices and collection schemes for E-waste management, with a view to minimize environmental impacts and maximize re-use, recovery and recycling of valuable materials. In developed countries, e-waste management is given high priority countries, while in developing countries, it is exacerbated by completely adopting or replicating the e-waste management of developed countries and several problems including, lack of investment, technological, financial, technically skilled human resources, lack of infrastructure, little available information on the e-waste situation, recovery of valuable materials in small workshops using rudimentary recycling methods, lack of awareness on the impacts of e-waste, absence of appropriate legislations specifically dealing with e-waste, approach and inadequate description of the roles and responsibilities of stakeholders and institutions involved in e-waste management, etc. This chapter provides the definition of e-waste, and presents information on generation of –andcomposition of e-waste, collection, treatment, and disposal systems. It also discusses the overview of e-waste collection schemes in different parts of the world with regional focus, and the best current practices in WEEE management applied indeveloped and developing countries. It outlines the illegal e-waste trade and illegal waste disposal practices associated with e-waste fraction. In this chapter, the terms “WEEE” and “E-waste” are used synonymously and in accordance to the EU, WEEE Directive.

Keywords: e-waste, illegal trade, recovery, collection, treatment, disposal system

1. Introduction

The information technology (IT) industry is an important engine of growth of any country. With the rapid development of technology, manufacturers now produce superior televisions, new and smarter mobile phones, and new computing devices at an increasing rate. People are enjoying what technology brings, surfing the Internet on their smart phones or tablets and watching high-definition movies on their televisions at home. As more and more electronic products are produced to fulfill the needs of people worldwide, more resources are used to produce these items. Hence, the rapid growth of computing and other information and communication equipment is driving the ever-increasing production of electronic waste (e-waste) [1]. The current e-waste encompasses a particularly complex waste flow in terms of the variety of products [2-3]. Over the next few years, one billion computers will be obsolete. In 2005, 8.3-9.1 million tons of e-waste was produced across the 27 members of the European Union (EU) [4]. By 2020, the total waste electrical and electronic equipment (WEEE) is estimated to grow between 2.5% and 2.7% annually, reaching a total of approximately 12.3 million tons. The reason is that the number of appliances entering the market every year is increasing in developed and developing countries [5]. Sales of electronic products in countries such as China and India and across Africa and Latin America are predicted to rise sharply in the next 10 years. Also, it is a higher growth pattern that will be influenced not only by need but also by changes in technology, design, and marketing [1]. The diverse waste generated due to advancement of technology may have significant impacts on the environment and public, if not properly stored, collected, transported, treated, and disposed of. Thus, around the globe, e-waste generation, treatment, and disposal are becoming issues of concern to waste management professionals, innumerable non-governmental organizations and citizens, and international agencies and governments, particularly in developing and transition countries. E-waste stream contains diverse materials, which requires special treatment and cannot be dumped in landfill sites, most prominently, hazardous substances such as lead, polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs), mercury, polybrominated diphenyl ethers (PBDEs), brominated flame retardants (BFRs), and valuable substances such as iron, steel, copper, aluminium, gold, silver, platinum, palladium, and plastics [6-7]. During the last decade, large amounts of diverse e-waste discarded by developing and transition countries, as well as a sizeable portion of the e-waste generated from developed countries and exported to developing and transition countries, has been rapidly piling up in developing countries impacting their emerging economies [8]. The management of e-waste in developing and transition countries is exacerbated by several factors, including illegal trafficking and unlicensed recycling of e-waste; lack of technological, financial, and technically skilled human resources; inadequate organizational structure required; and an inadequate description of the roles and responsibilities of stakeholders and institutions involved in e-waste management. In Africa, e-waste management is still in its infancy; characterized by little available information on the e-waste situation, the recovery of valuable materials in small workshops using rudimentary recycling methods, lack of awareness on the impacts of e-waste, and the total absence of policy specifically dealing with e-waste [9].

To describe the situation of e-waste around the world, this chapter provides the definition of e-waste. The next section of the chapter presents information on the generation, composition of e-waste, collection, treatment, and disposal systems. It also discusses the overview of e-waste collection schemes in different parts of the world with a regional focus, and the best current practices in WEEE management in developed and developing countries. It outlines the illegal e-waste trade and illegal waste disposal practices associated with e-waste fraction. In this chapter, the terms "WEEE" and "E-waste" are used synonymously and in accordance to the EU WEEE Directive.

2. Definition of e-waste

An electrical and electronic product can be classified as a product that contains a printed circuit board (PCB) and uses electricity. Much has been written about the e-waste problem, yet the definition of the term "electronic waste" is quite complex to define. Referring to scholarly literature on the topic, there is, as yet, no standard definition, as every country has its own definition of e-waste. The questions that arise, therefore is: What is to be called e-waste? Any electronic or electrical appliances, which are obsolete in terms of functionality? Products that are operationally discarded? Or is it both? [10]. Table 1 gives a list of the different definitions of e-waste.

Reference	Definition
European Union Waste Electronic and Electrical Equipment (EU WEEE) Directive [11]	Waste from electrical or electronic equipment refers to "*all components, sub-assemblies, and consumables, which are part of the product at the time of discarding*". In the Directive 75/442/EEC, Article 1(a), waste is primarily defined as "*any substance or object that the holder disposes of or is required to dispose of pursuant to the provisions of the national law in force*".
Basel Action Network [12] Puckett and Smith [13]	E-waste means "*discarded appliances using electricity, which include a wide range of e-products from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users*".
Organization of Economic Cooperation and Development (OECD) [14]	E-waste can be classified as "*any appliance using an electric power supply that has reached its end of-life*".
SINHA [15]	E-waste can be described as "*an electrically powered appliance that no longer satisfies the current owner for its original purpose*".
Solving the E-waste Problem (StEP) [16]	"*E-waste refers to the reverse supply chain that collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes*".

Table 1. Different definitions of e-waste.

Many researchers have established that a clear definition of e-waste is needed due to rapid technological changes and enhancement, which are shortening the lifespan of the electronic products [8-10]. To date, the widely accepted definition in different e-waste studies is by the EU WEEE Directive, which defines e-waste as "*Electrical or electronic equipment (EEE) which is* *waste, including all components, sub-assemblies, and consumables, which are part of the product at the time of discarding*" [11]. E-waste is usually described in terms of the cost and durability of products used for data processing (e.g., telecommunications or entertainment in private households and businesses) [17].

3. E-waste generation

The major problem associated with e-waste management is its ever increasing quantum. However, the e-waste quantities represent a small percentage of the overall municipal solid waste (MSW). Data on e-waste generation may vary between areas of a country because of the definitions of waste arising, technological equipment used, the consumption patterns of the consumers, and changes in the living standards across the globe [18]. Global e-waste generated per year amounts to approximately 20-25 million tons, most of which is being produced in rich nations such as the United States (US) or European Union member countries. The US, is the largest generator of e-waste, with a total accumulation of 3 million tons per year; and China is the second largest, producing 2.3 million tons each year. Brazil generates the second greatest quantity of e-waste among emerging countries [19].

In Malaysia, the volume of e-waste generated is estimated at roughly 0.8-1.3 kg of waste per capita per day, with an increasing trend of e-waste generation, which rose to 134,000 tons in 2009. Furthermore, the volume of e-waste in Malaysia is expected to rise to 1.1 million metric tons in 2020, at an annual rate of 14% [20]. In South Africa and China, e-waste production from old computers will increase by 200-400% from 2007 to 2020, and by 500% in India. In this same period e-waste from televisions will be 1.5-2 times higher in China and India; whereas in India, e-waste from discarded refrigerators will double or triple by 2020. For India, the volume of e-waste generated is 146,000 tonnes per year. However, these data only include e-waste generated nationally and do not include waste imports (both legal and illegal) which are substantial in emerging economies such as India and China [21]. The reason is that large amount of WEEE enters India from foreign countries without paying any duty in the name of charity [22-23]. The rate at which the e-waste volume is increasing globally is 5 to 10% yearly [24].

4. Composition of e-waste

E-waste normally contains valuable, as well as potentially toxic materials. The composition of e-waste depends strongly on factors such as the type of electronic device, the model, manufacturer, date of manufacture, and the age of the scrap. Scrap from IT and telecommunication systems contain a higher amount of precious metals than scrap from household appliances [6]. For instance, a mobile phone contains more than 40 elements, base metals such as copper (Cu) and tin (Sn); special metals such as lithium (Li) cobalt (Co), indium (In), and antimony (Sb); and precious metals such as silver (Ag), gold (Au), and palladium (Pd) [25-27]. Special treatment of e-waste should be considered to prevent wasting valuable materials and rare elements. Materials such as gold and palladium can be mined more effectively from e-waste compared to mining from ore [28]. By contrast, e-waste contains PBDEs, which are flame retardants that are mixed into plastics and other components. Circuit boards found in most of the electronic devices may contain arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), and other toxic chemicals. Typical printed circuit boards treated with lead solder in electronic devices contain approximately 50 g of tin-lead solder per square meter of circuit board [7]. Obsolete refrigerators, freezers, and air conditioning units contain ozone depleting Chlorofluorocarbons (CFCs). The prominent materials such as barium, cadmium, copper, lead, zinc, and other rare earth metals are contained in end-of-life (EOL) cathode ray tubes (CRTs) in computer monitors, and televisions. For example, items such as leaded glass provide protection against X-rays produced in the picture projection process in CRTs [6]. The average lead in CTR monitors is 1.6-3.2 kg. Thus, the US and other developed countries in the EU and Japan have banned the disposal of cathode ray tubes in landfills because of their toxic characteristics. A critical challenge in designing and developing strategies to manage e-waste is the changing composition of the many constituents due the advancement of technology, particularly in the electronic components [24]. It is against this background that e-waste recycling and disposal methods ought to keep pace with the changing composition of e-waste. Several factors influence the composition of e-waste, including economic conditions, availability of a reuse market, and infrastructure of the recycling industry, waste segregation programs, and regulation enforcement. Figure 1 illustrates the distinctive materials in a WEEE.

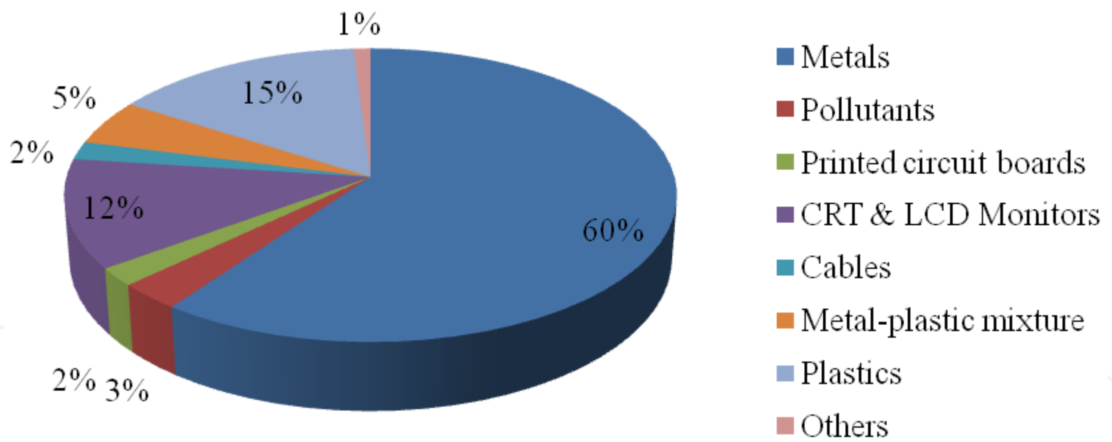

Figure 1. The distinctive contents of a WEEE. Source: Adapted from [9].

5. E-waste data for several countries across the globe

5.1. Amount of e-waste collected and treated

E-waste generated from the different diverse sources is normally collected as a whole unit or sub-unit of functional equipment. In many instances across the globe, whole units of e-waste have been categorized as e-waste. Based on the number of discarded information communication technology (ICT) devices collected in Europe, computers, cell phones, fixed-line telephones, televisions, and radios are the major electronic products, and together they amounted to 11.7 million tons in 2007. In 2004, approximately 75,000 tons of WEEE were collected, classified, disassembled, and then processed in Switzerland, compared with the collection of approximately 68,000 tons in 2003 [29].

In developing and transition countries, little consideration is given to the quantification of the e-waste collected. The reason is that in pre-reprocessing stages, collection of the e-waste is mostly undertaken by the unorganized sector of scrap dealers/traders or peddlers. As a result, this information is invisible to the statistics collection system, which makes quantification of e-waste very difficult in developing and transition countries [27]. More precise figures regarding unused electronic and electrical equipment/waste electronic and electrical equipment (UEEE/WEEE) are not available because the customs data do not distinguish between used and new equipment and the import statistics reveal only total values [29]. Based on the current understanding on e-waste management, research studies suggest that to achieve sustainable development goals associated with waste management would require successful establishment of baseline levels of information from which more informed e-waste management and policy decisions can be made [30]. Similarly, to effectively manage e-waste could require establishment of separate collection channels that would be environmentally friendly. This could result in the reduction of e-waste generated and its environmental impacts [31].

In the EU, the EU WEEE directive clearly imposes collection, recovery, and recycling targets on its member countries. Thus, it stipulates a minimum collection target of 4 kg/capita per year for all the member states. These collection- and weight-based recycling targets seek to reduce the amount of hazardous substances disposed into landfills and to increase the availability of recyclable materials that indirectly encourages less virgin materials consumption in new products [11]. Switzerland is the first country in the world to have established and implemented a formal e-waste management system that has recycled 11 kg/capita of WEEE against the target of 4 kg/capita set by the EU. One-third of electrical and electronic waste in the EU is reported as separately collected and appropriately treated. In 2006, Germany collected and treated about 754,000 tons of e-waste according to the ElektroG system, while other EU member states collected about 19,000 tons. It was also forecasted that IT and telecommunications equipment put on the market were 315,000 tons, and the waste collected and treated in the system according to ElektroG was about 102,000 tons (7,000 tons of this was collected from other EU countries) [29]. This shows the effective collection and treatment of e-waste in the EU. The introduction of the extended producer responsibility (EPR) scheme in 2003 was the most important step in South Korea, and about 70% of e-waste was collected by producers. Over the same period, the amount of e-waste reused and recycled was 12% and 69% respectively. The remainder was sent to landfill sites or incineration plants, accounting for 19% [32].

5.2. Amount of e-waste disposed

The scientific and environment friendly disposal of e-waste is critical. Relevant past studies on e-waste management confirmed that rapid growth combined with rapid product

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obsolescence are the most important factors making discarded e-products one the fastest growing waste fraction, accounting for 8% of all municipal waste in the EU. If not disposed of properly it could lead to significant negative environmental impacts. The average for developing and transition countries was 1% of total solid waste, which increased to 2% in 2010 [33]. Developing and transition countries, especially those in Africa and Asia, are the primary destinations for e-waste dumping, despite these countries lacking basic disposal technologies or facilities [34].

In 2012, more than 70% of the total electronic waste collected worldwide was actually exported or discarded by developed countries [35]. In the US alone, 130,000 computers and more than 300,000 cell phones are disposed each day, and an estimated 80% of the generated e-waste is sent to less-developed countries [36]. In 2007 in the US, 410 thousand tons were recycled (13.6%), and the rest was improperly discharged in landfills or incinerated. Between 2003 and 2005, approximately 80-85% of the e-waste ready for EOL management ended up in US landfills. A related study about e-waste management in the US pointed out that in 2009, enormous quantities of e-waste (82.3%) was disposed in landfill sites and incinerators, while 17.7% went to the recyclers [26]. In the EU, it is shown that two-thirds of this waste stream is potentially still going to landfills and to sub-standard treatment sites in or outside the EU. In China, huge volumes of e-waste have been discarded in recent years as people more frequently replace their old home appliances with new ones [37-39].

A relevant case-study on e-waste management pointed out that it is not possible to make an overall comparison between different countries, even if they are in the same continent, as the definitions in legislation and categorization of e-waste streams differ. Nevertheless, it is established that the main volumes of e-waste reside in developed countries [40].

6. Collection, treatment, and disposal systems

Collection, treatment, and disposal systems are critical elements of e-waste management. Most developed countries have framed conventions, directives, and laws aimed at fostering proper collection, treatment, and recycling of e-waste, as well as safe disposal of the non-recyclable components [36]. These include the EPR, product stewardship, advance recycling fund (ARF), the 3Rs or Reduce, Reuse, Recycle initiative, etc. For the EU, two directives have been promulgated to place an obligation on the producers of e-goods to take back EOL or waste products free of charge in an effort to reduce the amount of waste going to landfills [37]. However, in developing and transition countries, e-waste is treated in backyard operations, using open sky incineration, cyanide leaching, and simple smelters to recover precious metals mainly copper, gold, and silver—with comparatively low yields—and discarding the rest with municipal solid waste at open dumps, into surface water bodies and at unlined and unmonitored landfills [35], thereby causing adverse environmental and health effects. Table 2 presents a comparison of typical e-waste treatment processes in developed and developing countries.

Developing countries	Developed countries
“Informal” sector	Formal sector
Manual dismantling	Manual dismantling
Manual separation	Semi-automation separation
Recovery of metals by heating, burning, and acid leaching of e-waste scrap in small workshops	Recovery of metals by the state-of-the-art methods in smelter and refineries

Table 2. Comparison of typical e-waste treatment processes in developed and developing countries [41].

6.1. Disposal system

Disposal of e-waste is mainly through landfilling. Most often, the discarded electronic goods finally end-up in landfill sites along with other municipal waste or are openly burnt releasing toxic and carcinogenic substances into the atmosphere. In developing and transition countries the disposal of e-waste in the informal sector is very rudimentary so far as the safe techniques employed and practices are concerned, resulting in low recovery of materials [38]. Table 3 presents a comparison of typical disposal systems in developed and developing countries.

Developed countries	Developing countries
Incineration with MSW	Opening burning
Landfill disposal	Open dumping

Table 3. Comparison of a typical e-waste disposal systems in developed and developing countries [13].

E-waste management is different between developed countries and developing and transition countries. Developing and transition countries do not have guidelines and information campaigns on the fate of e-waste. Especially, less sophisticated disposal systems are used, from open burning and dumping to uncontrolled landfill sites, which pose significant environmental pollution and occupational exposure to e-waste-derived chemicals [31]. Serious challenges in the disposal of e-waste were analyzed across developing countries such as Brazil [19], China [42], and India [43], outlining the difficulty to implement/enforce existing regulations and clean technologies backed by lack of capacity building and awareness. In contrast, developed countries have devised sophisticated disposal schemes and high-cost systems, which are less hazardous to handle waste. However, a comprehensive overview of the situation is constrained by the availability of data. This means that the differences in the socio-economic and legal contexts between typical developing and developed countries’ scenarios limit e-waste management in developing and transition countries. The regulations that guide the disposition of e-waste in developing countries is mostly fragmented and lack monitoring, while in developed countries the regulations are stringent and there is effective monitoring [36].

7. An overview of e-waste collection schemes in different parts of the world with a regional focus

In general, citizens must sort and segregate e-waste to divert e-waste from mixed municipal waste collection schemes and landfills due to the heteremeneous materials it contains. It needs to be stored, and then transferred to the curbside or transported to an offsite collection site [27]. Although research has supported that curbside collection is the most convenient collection system for households, offsite drop-off remains attractive to waste management authorities. This is because curbside collections are regarded as expensive, time-consuming to design, implement, and operate [28].

In essence, a separate, parallel collection and management scheme is required, organized by the authorities, the producers, or retailers. Compared to simple or commingled collection, such as single-stream collection, source separation imposes additional efforts on citizens regarding material segregation and drop-off and, thus, convenience is of paramount importance [34]. In developed countries, e-waste is collected to recover some materials of value and to be safely rid of the lead, cadmium, mercury, dioxins, furans, and such toxic materials they contain. On the other hand, in developing countries, e-waste is collected principally to recover a few metals of value. E-waste collection is logically a profit-driven activity. E-waste contains a huge volume of different engineering materials that can be reused via available and evolving technologies [9].

7.1. The Asian region

In Malaysia, a planned infrastructure is being promoted for whole units of WEEE to be collected from households, business entities, and institutions [20]. The Department of Environment (DoE) and the Japanese International Cooperation (JICA) are trying to develop an e-waste collection model for household items in Penang state for the very first time. This model is expected to be used to make a countrywide drive after the model’s test run, which may happen in the next few years. However, this model has limitations, and only can ensure the collection of a small portion of e-waste. Thus, there is no engineering analysis on material characteristics, remanufacturing potential, and economic benefits, and an optimization analysis is not yet planned. Moreover, there is no reverse logistic system in this model. The e-waste collection activities in Malaysia include: DoE-licensed contractors, retailer’s collection, environmental working groups, voluntary collection organization, social organizations, informal scrap collectors, street buyers, scavengers, traditional hawkers (Surat khabar lama), and manufacturers’ initiatives such as Panasonic Malaysia ECOMOTO Take back, Nokia Malaysia, Dell Malaysia HP, and Pikom (National ICT) [39].

In other Asian countries, collection of most -waste materials and components remains in the hands of the informal sector. "Scavenging" or the informal sector is the predominant collection scheme of e-waste in the Asian region. Using inappropriate methods, this poses a severe threat to the environment and health of the workers [41]. For instance, in China, Taiwan, Thailand, the Philippines, Indonesia, and other neighboring countries [42], this informal stream of e-waste collection is not under regulation, and most of the e-waste ends up in landfills through the informal stream. Furthermore, collection systems and procedures in the region are very loose, and there is limited established market for finished products resulting from recycling [41]. Customers need to be given incentives to return their EOL e-products back to the collection centers. In India and China, studies equivocally state that consumers look for economic benefits for discarding their e-waste. Thus, the Chinese residents, in the likelihood of a take-back regime, reportedly seem to prefer the pay-in-advance scheme against the deposit-refund route favored by residents in India. There exists a very well networked and effective door-to-door collection network in India [43]. China has established special recovery industrial parks in Tianjin, Taicang, Ningbo, Linyi, Liaozhong, Taizhou, and Zhangzhou in order to promote efficient and environmentally friendly recovery of original and imported metals. The collection of discarded household electronic and electrical equipment in China is still dominated by the so-called informal individual collectors (peddlers). They provide a door-to-door service by paying marginal fees to e-waste owners and then sell them to e-waste dealers [44].

7.2. The European Union context

Consumers in Europe use municipal collection, retailer collection, social organization collection, and the re-use market to collect e-waste. The so-called municipal collection is performed by local authorities (municipalities or counties). It is pointed out that some municipalities collect the WEEE themselves, while others themselves, while others contract with other parties to collect to collect it on their behalf. Municipal collection activities are managed and financed by public waste management entities, whereby drop-off points and doorstep collection are used [45]. Retailer collection is performed either by the retailers themselves or by their logistics partners who deliver new appliances to consumers. Social organization collection is performed in cooperation with several members of the reverse supply chain, with the purpose of providing a material input to and a financial benefit for the social organizations. The re-use market extends the use phase of appliances, thereby delaying the final discarding by the ultimate owner/user of the appliance into municipal, retailer, or social collection [45-46]. Germany has developed a curbside collection scheme and is already achieving remarkable success in e-waste management andrecycling. The typical collection channels in the EU, from dismantling through pre-processing until end-processing, lead to the safe disposal or processing of e-waste [41].

7.3. The situation in the US and Canada

The US and Canadian provinces are increasingly adopting EPR and product stewardship (PS) schemes for WEEE. For instance, in the state of Maine in the US, the WEEE management program is based on a PS scheme, with the active participation of retailers [47]. Three American-based non-governmental organizations (NGOs) are particularly active in e-waste issues. The Basel Action Network (BAN), Silicon Valley Toxic Coalition (SVTC), and Electronics Take-Back Coalition (ETBC) constitute an associated network of environmental advocacy NGOs in the US. The three organizations' common objective is to promote national-level solutions for hazardous waste management [7]. A recent initiative has been e-Stewards, a system for auditing and certifying recyclers and take-back programs so that conscientious consumers know which ones meet high standards. Canada is among the countries developing systems based on these principles and EPR. Also, Canada has well-developed and advanced collection systems. In the US, Apple, Sony, Sharp, Mitsubishi, Samsung, Hewlett-Packard, Dell, LG, Lenovo, Panasonic, and Toshiba have free collection point or mail-in take-back programs of their products [48].

7.4. Japan and Brazil

Japan has a door-to-collection scheme to separate e-waste from being mixed with other municipalcollection schemes. The retailers and the municipality, in some cases, are obliged to transfer the collected units to the producers' designated collection points and subsequently pass on the recycling fee to the producers. The producers are mandated to collect e-waste from their designated collection points and achieve the recovery targets set under the legislation [49]. In Brazil, "e-scrap" can be disposed of and recycled through three mechanisms: social organization collection, manufacturer collection, and retailer collection [50].

Overall, the waste collection infrastructure in developing countries is characterized by a high level of informality. Thus, a certain level of informality will prevail even when a regulated e-waste management system becomes operational [41]. Evaluating the e-waste management in developing and transition countries, it has been established that the informal recyclers will continue to collect major components of e-waste with economic value from individual households. Similarly, research showed that the major challenge is to guide the informal sector toward systems that could work in a regulated environment in the future [31]. Hence, increasing attention on incentivizing individual and corporate consumers to dispose potentially harmful WEEE into formal collection systems would systematically improve the effectiveness of e-waste management systems. Consequently, financial plan could provide compensation for the return of obsolete equipment to make the system more effective and sustainable [51].

8. The best current practices in WEEE management applied in developed and developing countries

Managing the increasing quantum of e-waste effectively and efficiently-in terms of cost and environmental impact is a complex task. Thus, the adoption of best practices and implementation of mitigation measures are important steps to manage e-waste products, particularly at the EOL. Hence, developing and developed countries have responded to these growing quantities of e-waste and their potential impacts by developing various disposal pathways, several measures, and legal frameworks to properly manage such waste [43]. It is established that when developing an effective e-waste management system, the following should be considered:

- Collection of e-waste from the source of generation and transportation to disposal sites and treatment facilities require special logistic requirements [2].
- Disposal of e-waste requires specialtreatment to minimize impacts on the environment; e-waste contains many hazardous substances that are extremely dangerous to human health and the environment.
- E-waste is a rich source of precious metals such as gold, silver, and copper, which can be recovered and recycled/reused into the production cycle [50].

Significant differences exist in the management of e-waste between developed countries and emerging economies. Many developed countries have understood the importance of developing and implementing regulatory approaches (laws and regulations) to tackle the ever increasing quantum of WEEE, and framed and formulated various laws and regulations to restrict the negative impact of WEEE on occupational health and the environment [52].

8.1. The best current practices in WEEE management applied in developed countries

8.1.1. The EU context

Switzerland is the first county in the world to develop and implement a well-organized and formal e-waste management system for collection, transportation, recycling/treatment, and disposal of e-waste [28]. Thus, the EPR principle is used as a framework to manage e-waste. The EPR makes manufacturers/producers and exporters of products responsible for the environmentally sound handling, recycling, and disposal of the e-waste [53]. Two-based Producer Responsibility Organizations (PROs) are responsible for the management of e-waste. The Swiss Association for Information Communication and Organizational Technology (SWICO) and Stiftung Entsorgung Schweiz (S.E.N.S.) constitute the PROs in the Swiss system. The two PROs are responsible for the management and operations of the system on behalf of their member producers covering different parts of WEEE, as defined by the European WEEE directive [11, 53]. In the Swiss system, consumers of EEEs are required to pay ARF when purchasing new ones for the daily operation of the system such as collection, transport, and recycling/disposal. The ARF requires that the end consumer pays the recycling fee, which is equivalent to the difference between the total system cost and the total recovered value from the e-waste, and ensures that the necessary finances for the system as the fees are collected in advance. Analyses of the Swiss system showed that the consumers willing to dispose of their e-waste are free to deposit old or obsolete appliances, regardless of the brand or year of manufacture free of charge to any retail shop or 500 official collection points. The ARF prevents the illegal disposal of e-waste since consumers are willing to pay small amounts of money when purchasing the new products rather than EOL, which they will ultimately have to dispose [54].

To ensure the smooth functioning of the Swiss system, multiple levels of independent controls on material and financial flows at every stage have been formulated that check on free riding and pilferage, as well as ensure that the recyclers maintain quality and environmental standards [53]. This also prevents the illegal import and export of e-waste to and from

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Switzerland. Hence, Switzerland does not permit the export of e-waste to non-OECD countries and has been a signatory to the Basel Convention Ban Amendment [54].

In July 2001, Sweden executed its WEEE management regulation to ensure the appropriate treatment of WEEE. For instance, consumers can send back old products to retailers when they buy a similar new product (old-for-new or new-for-old rule). Moreover, household consumers can leave their WEEE at municipal collection points, while institutional and enterprise consumers are responsible for covering the expense of treating WEEE. Thus, municipalities are responsible for managing these collection points for household consumers, while manufacturers are responsible for covering the costs of WEEE collection and treatment. Meanwhile, a retailer's responsibility is to accept WEEE from consumers under the old-for-new rule [55].

8.1.2. Japan

Japan has adopted a new legal framework in [56] to kick-start its own WEEE recycling system incorporating EPR with a view to establish a sound material-cycle society that promotes the 3R principle. Such a law was necessitated by the fact that proper treatment of e-waste would enable proper resource recovery and reduce dependence on landfill. A unique feature of the Japanese EPR law is that it is primarily based on the principle of shared responsibility wherein the responsibilities of different stakeholders are explicitly shared. For instance, according to the Home Appliance Recycling Law (HARL), retailers are mandated to collect used products, consumers are responsible for financing recycling and transportation by paying recycling fees to the retailer at the point of disposal, and producers are mandated with setting-up pretreatment plants and collection networks. The above law covers four major e-waste products, namely air-conditioners, televisions, laundry machines, and refrigerators [57].

On the other hand, bulk and business consumers may either engage the treatment of e-waste at their own expense or return to the retailer by paying the requisite recycling fees. The law for the management of e-waste from personal computers (PCs) from the business sector also came into effect on April 2001, while those from the household sector came under EPR law on October 2003 [56]. However, for computers, the costs of recycling are borne at the point of sale, as opposed to at the point of disposal for products under HARL. Yet another law, the Small-sized Home Appliance Law was enacted on April 2013 to cater for small electronic and electrical home appliances such as mobile phones, gaming machines, small personal computers, etc. The new law, which covers about 100 items, does not require consumers to pay recycling fees. Under this new law, the concerned municipality is responsible for setting up collection centers, from where collected waste is to be sent to certify recycling companies. Furthermore, each municipality is stipulated to design their own collection centers and identify the products to be collected [57]. Home appliances are taken back by retailers or secondhand shops according to the flow in Figure 2. However, problems with the recycling system include inelastic recycling fees, illegal dumping, illegal transfer by retailers, and the limited number of target appliances [58].

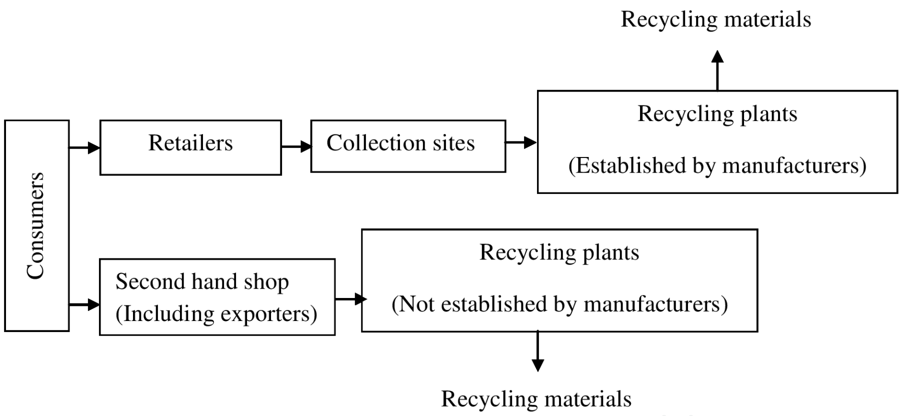

Figure 2. Flow of the take back system in Japan. Source; Adapted from [58].

8.1.3. Singapore

In Singapore, retailers have established commercial take-back schemes for their products. The retailers set prices of used mobile phones based on the quality. It is established that the mobile phones are leased during the contract period (e.g., 2 years), at a lower cost than the sales price. As a result, approximately 95% of used mobile phones are taken-back. The second-hand mobile phone market is well-developed in Singapore, with many retail shops dealing in second-hand phones [59]. This shows effective the collection of EOL e-products by retailers in Singapore.

8.2. The best current practices inWEEE management applied in developing countries

8.2.1. South Korea

Korea has promulgated the Act on the Promotion of Conservation and Recycling Resources (also called the Waste Recycling Act), which took effect in 1992. The act regulated two home appliances, television and washing machines, together with air conditioners and refrigerators. Other statutory instruments include Waste Deposit-Refund System for limited categories of home appliances, packaging materials (e.g., glass, plastics, and cans), and other items (e.g., lubricating oil, batteries, tires, and fluorescent lamps) as part of the Act in 1992; modification of the Waste Recycling Act was made to promote effective collection and recycling of materials and promulgate EPR regulation for items covered by the Waste Deposit-Refund System for personal computers and monitors; and the Act on the Resource Recycling of WEEE and EOL Vehicles, aimed at reducing the amount of e-waste going to landfills and incinerators [60]. In 2003, the EPR system was enforced to promote recycling practices [61].

8.2.2. India and China

China and India have promulgated schemes similar to the EPR. EPR involves producers taking more responsibility for managing the environmental impacts of their products throughout their lifecycle, particularly at the end of their life. Producers that manufacture the EPR products must collect and recycle an assigned quantity based on a certain percentage of their annual production volume. In India, more relevant and important regulation have been issued in the past decade by the Ministry of Environment and Forests (MoEF), and the most important is the letter no. 23-23/2007-HSDM dated March 12, 2008, the guidelines for environmentally sound management of e-waste, which aims to provide guidance for the identification of various sources of e-waste, and outline procedures for environmentally sound handling of e-waste [61]. On May 14, 2010, the MoEF issued a draft of the E-waste (Management and Handling) Rules, 2010. The rules clearly stipulate producer responsibility for the proper collection of e-waste through an appropriate take-back system on the same lines as the European EPR directive [62]. However, this regulation does not describe the specific handling and treatment practices of WEEE. The Hazardous and Waste Management Rules, 2008 and Municipal Solid Waste Management Rules, 2004 aim at addressing the hazardous and non-hazardous materials found in e-waste, but are not specific at defining the roles of the different stakeholders in e-waste management. The main problem in India is the administrative delays to enforce these regulations [63]. The Chinese government has introduced legislation and developed infrastructure on WEEE and the removal of hazardous substance (RoHS) according to EU directives [64].

8.2.3. Brazil

The Brazilian government has developed general environmental regulations applicable to e-waste management, such as Act 12.305 of August 2, 2010, which established a National Policy on Solid Waste, and "reverse logistics" obligation for e-waste, and Decree 7.404 of December 23, 2010. The Committee of the National Policy on Solid Waste (CNPSW) was established to support the structuring and implementation of this policy through the articulation of government agencies. Thereafter, a thematic group (TG) made of different stakeholders, including government departments, industries, municipalities, representatives of NGOs, and scavengers was set up. Only São Paulo state has passed its own e-waste legislation based on EPR, Law 13576, on July 6, 2009 [19].

8.2.4. The African Context

As early as 2004, several projects were successfully initiated in three South African provinces (namely KwaZulu-Natal, Western Cape, and Gauteng) with support from the Global Knowledge Partnerships in e-Waste Recycling program, which was initiated by the Swiss State Secretariat for Economic Affairs (SECO) and implemented by the Federal Laboratories for Materials Testing and Research (EMPA). It is established that some (inter)national-based IT corporations have shown increasing commitment to set up and support initiatives nationwide to address the challenge of e-waste. In order to deal with the sustainable and environmentally sound e-waste management system for the country, the e-Waste Association of South Africa (eWASA) was established on 2008. However, these initiatives lack efficient monitoring and enforcement. As a result, improper e-waste management still exists despite these initiatives [65].

Despite the absence of regulations concerning the specific collection and disposal of e-waste in developing countries some countries provide separate schemes for certain types of e-waste. Increased public awareness and government attention to the problems emanating from e-waste have prompted few manufacturers from developing countries to establish individual take-back schemes for specific products as a part of their corporate social responsibility and green image. In brief, the management schemes are categorized as follows:

- Mandatory product take-backs, as for example in Taiwan
- Voluntary take-back strategies, as for example China and India

Take-back policies in the form of disposal (or recovery) fees either at the time of disposal or at the time of purchase (advance recycling fees or advance disposal fees) have been developed. For instance, the Japanese model argues for both approaches: advance fees for computers, and fees at the point of disposal for home appliances. Conversely, the Californian and Taiwanese models favor advance recycling fees for all products, which are typically used to fund the state-controlled recycling system [66-67]. Advance disposal or recovery fees have the advantage of being visible to all stakeholders that influences better future planning at the downstream end. Additionally, fees charged at the point of disposal might lead to an indifferent disposer who, in all likelihood, might be tempted to illegally dump the used products or perpetually store them [61].

Over the recent years, regulation efforts have been implemented to remove hazardous items or optimally recover the main recyclable materials. Others are aimed at increasing the collection and recycling rates of e-waste through diverse collection programs, encouraging manufacturers to develop more environmentally sustainable products, and requiring manufacturers to take responsibility to recycle their products [41]. The Best-of-2-Worlds (Bo2W) philosophy has been introduced, which seeks technical and logistic integration of the “best” pre-processing facilities in developing and transition countries to manually dismantle e-waste and the “best” end-processing strategies to treat hazardous and complex fractions in international state-of-the-art end-processing facilities [67]. Alternatively, eco-friendly product designs can also reduce the environmental pollution caused by recycling e-waste scrap. At present, Design for Environment (DfE) is attracting much attention in the world as a new method to solve environmental pollution. DfE principle in the product design is a process to significantly reduce the environmental impact of products being put into the market. It is pointed out that DfE is intended for: easy disassembly to encourage recycling of home appliances; recycling by using recyclable materials; energy saving; and reducing hazardous material such as Pb, Hg, Cd, and hexavalent Cr [68]. If DfE, in particular, becomes more widespread, we can expect significant mitigation of environmental damage caused by recycling e-waste scrap [66].

9. An outline of the illegal e-waste trade and illegal waste disposal practices associated with e-waste fraction

9.1. The illegal e-waste trade

Across the globe, high volumes of e-waste have been discarded in recent years. Despite the fact that many countries have already organized e-waste regulations, there are additional problems with the import/export of e-waste. For instance, in industrialized countries such as the US, Japan, and the EU, recycling operations have set high environmental and social standards, which trigger the illegal exportation of WEEE to developing and transition countries [41]. The developing and transition countries lack cleaner technologies, waste minimization measures, and environmental sound management systems. As a result, the items are treated, recycled and/or reused with less consideration for environmental protection and public safety and health [42].

Several countries have ratified the Basel Convention on trans-boundary movement of hazardous waste. It specifies the relevant requirements of governments exporting hazardous waste, and stipulates the responsibility of the government of the importing country. However, because of the lack of management systems for secondhand e-products and e-scraps, these items are not covered by the convention's rules [19]. The Basel Convention does not solve the new environmental problems caused by the recycling of e-waste. Over the recent years, the exportation of secondhand electronic devices from developed countries to developing and transition countries continues through clandestine operations, legal loopholes, and by countries that have not ratified the convention. For instance, about 2 million secondhand televisions, approximately 400,000 units are exported from Japan to the Philippines, annually. However, inappropriate recycling and final treatment processes such as open burning of wires and improper crushing of CRT tubes has been observed at or near dumpsites in Manila. Amendments to the Basel Convention are necessary to prevent the exportation of hazardous from developed countries to developing and transition countries for any purpose (even for recycling) [69].

China, Vietnam, and Cambodia have built up their own legal frameworks to deal with the import of secondhand items and hazardous wastes. For instance, in 1996, Cambodia banned the importation computers because of concerns about the possibility of spreading virus infections into domestic computer systems. Nevertheless, e-waste scrap is not subjected to any legal regulations [70].

In 2000, China introduced a complete ban on the importation of secondhand EEE. It also prohibited the importation of printed circuit boards [66]. In 2001, Vietnam followed suit to introduce the ban on importation of secondhand EEE, including home appliances and computers. Between 2004 and 2006, Vietnam introduced laws to tighten the ban on the importation of secondhand EEE (with the promulgation of Governmental Decree No. 12/2006/ND-CP) and re-exportation of e-waste scrap by the Minister for Trade (Decision No. 5678/VPCP). Along with laws banning the importation of secondhand EEE, relevant prohibitions on the importation of e-waste scrap for any purpose and on the dismantling of e-waste scrap have been enacted in July 2005. Although bans on the importation of secondhand EEE and printed circuit boards have been introduced in China and Vietnam, research studies pointed out that due to the demand for used electronic products and used parts, significant proportions of these materials still find their way into these two countries. In addition, these countries lack effective implementation of policies and monitoring measures. For instance, China allows the importation of secondhand EEEs to be imported as long as they are built and then re-exported. It is predicted that annually, some 57,700 tons of e-wastes were illegally imported, of which 8,470 tons were exported again. Also, mandatory removal results in spreading of improper recycling activities to other places. Given this background, it is clear that a major portion of e-waste scrap, such as printed circuit boards, has been, and is being, recycled or smuggled into Vietnam, China, and Cambodia [71].

The illegal trade of electrical and electronic waste to non-EU countries continues to be uncovered at EU borders. Past research studies confirmed that significant proportions of materials are still exported illegally outside of the EU member states because recycling companies, scrap dealers, brokers, and the so-called re-use companies take advantage of low dumping costs and environmental standards [44]. Illegal dumping remains a serious problem in Japan, and some e-waste is exported overseas as reusable parts [37]. China, along with Peru, Ghana, Nigeria, India, and Pakistan are the biggest recipients of e-waste from industrialized countries [25, 72-73]. Other leading recipient countries of e-waste are Singapore, Malaysia, Vietnam, Philippines, and Indonesia [5, 21, 74]. Approximately 500 containers with electrical and electronic equipment reach Nigeria every month [75]. Some researchers estimate that approximately 400,000 used computers are imported every month. Of these, only approximately 50% are functional. Approximately 45% of the equipment comes from Europe and the USA each, and the other 10% from Asia. This situation was also found in Ghana, where computers, televisions, and monitors were the most common imports. According to the available data, around 300 containers of UEEE/WEEE reach Ghana every month through the ports of Tema. The highest number of equipment from the EU comes from Germany, the Netherlands, and the UK. It was established that approximately 75-80% of the imported UEEE/WEEE cannot be reused [75-76].

9.2. An outline of the illegal waste disposal practices associated with e-waste fraction

In developing and transition countries, formal recycling of e-waste using efficient technologies and facilities is rare; therefore, e-waste is managed through various low-end management alternatives, such as disposal in open dumps, backyard recycling, and disposal into the environment, such as surface water, conventional landfills, etc. The majority of the unusable components are thrown away arbitrarily, polluting the environment and water sources [73]. Developing and transitional countries have not yet established official e-waste recycling facilities. Some developing countries, such as South Africa, Indonesia, India, etc., have industrial areas where recycling facilities and plants have been built [74]. However, backyard recycling of PCs, television sets, etc. is a common practice. For instance, individuals from the informal sector usually recover precious materials from e-waste, such as gold from the integrated circuit (IC) socket or IC chipset. Using their bare hands and without wearing any personal protective clothing (PPP) for safety and health protection mask, they burn ICs and mix the residue with other chemicals (e.g., nitric acid (HNO3), selenium, etc.) to recover gold [77]. This process generates waste water containing heavy metals that exceed World Health Organization (WHO) threshold values of waste water regulations (e.g., Cu, Cr, Co, Pb, nickel (Ni), Sn, and zinc (Zn)) [41].

10. Impacts of e-waste

The uncontrolled recycling of WEEE known as “backyard recycling” by the so-called informal sector is the main concern in non-OECD countries such as India, China, etc. Informal recycling is the most pressing environmental issue associated with e-waste [78]. Relevant case-studies about informal recycling of e-waste performed by [41, 77] pointed out that primitive tools and methods such as open burning of plastic waste, exposure to toxic solders, and acid baths to recover valuable materials and components from WEEE with little or without safeguards to human health and the environment result in the pollution of the land, air, and water. Guiyu in Guangdong Province, China, is one of the widely known examples of a center of improper recycling of printed circuit boards. Health effects of crude e-waste disposal methods have been reported. These include elevated levels of exposure of toxins in air, soil, water, and human tissue. This is because there are no criteria for reusability and no legally binding guidelines aimed at providing a common understanding practices of handling in developing and transition countries to manage e-waste. Besides Guiyu, there are several lesser printed circuit board recycling areas in Guangdong Province, such as in Guangzhou, Dongguan, Foshan, Shunde, Zhongshan, and Shenzhen [79].

Recycling of e-waste scrap is polluting not only the water but also the soil and the air. A recent study on recycling of e-waste [80] pointed out that the increasing concentrations of persistent organic pollutants (POPs), such as polychlorinated dibenzo-p-dioxins dibenzofurans (PCDD/Fs), PBDEs, polycyclic aromatic hydrocarbons (PAHs), and PCBs, and heavy metals were detected in the Guiyu air because of incomplete combustion of e-waste. Higher concentrations of POPs and heavy metals compounded more favorable conditions for severe pollution of soils. Other environmental pollutions accrued from recycling printed circuit boards have been observed in some areas in Vietnam. A multitude of health consequences may result from prolonged exposure to these hazardous materials, such as negative birth outcomes, cancer, long-term and permanent neurologic damage, and end-organ disease of the thyroid, lungs, liver, and kidneys [81]. Significant environmental impacts and risks on workers by crude disposal processes were analyzed across Indian cities, such as Bangalore [10], outlining the increasing concentration of elements such as Cu, Zn, In, Sn, Pb, and bismuth (Bi) in soil near informal recycling shops. As a result, increasing concentrations of Cu, Sb, Bi, Cd, and Ag were reported in the hair samples of the workers [82]. The lax or zero enforcement or implementation of existing regulatory framework or low level of awareness and sensitization, and inadequate occupational safety for those involved in these processes exacerbate e-waste management in developing countries compared to the EU and Japan, which have well-developed initiatives at all levels aimed at changing consumer behavior [31]. Therefore, there is need for developing countries to adopt effective strategies to encourage re-use, refurbishing or recycling e-waste in specialized facilities to prevent environmental contamination and human health risks [83].

11. Conclusions

E-waste management is a great challenge for governments of many countries. It contains hazardous constituents that may negatively impact the environment and affect human health if not properly managed. Developed countries have implemented restrictive policies to manage e-waste. However, developing and transition countries harbor in their economies an entrenched business sector that use harmful methods to retrieve valuable materials from e-waste. These methods are harmful to both humans and the environment. These informal sectors in developing and transition countries may best be reformed by specifically targeting the most unfriendly environmental practices. Hence, there is an urgent need to integrate the informal sector with the formal sector in order to separately collect, effectively treat, and dispose of e-waste, as well as divert it from conventional landfills and open burning, thus minimizing public health and environmental impacts. The competent authorities in developing and transition countries need to establish mechanisms for handling and treatment of e-waste. Increasing information campaigns, capacity building, and awareness is critical to promote environmentally friendly e-waste management programs. In developing and transition countries, significant attention is needed in developing information management systems for defining what contributes to e-waste, generation and management. Increasing efforts are urgently required on improvement of the current practices such as collection schemes and management practices to reduce the illegal trade of e-waste, and also to protect the environment and public health. Reducing the amount of hazardous substances in e-products will also have a positive effect in dealing with the specific e-waste streams since it will support the prevention process.

Glossary of terms and acronyms

Ag; Silver

ARF; Advance Recycling Fund

As; Arsenic

Au; Gold

BAN; Basel Action Network

BFRs; Brominated Flame Retardants

Bi; Bismuth

Bo2W; Best-of-2-Worlds

Cd; Cadmium

CFCs; Chlorofluorocarbons

CNPSW; Committee of the National Policy on Solid Waste

Co; Cobalt

Cr; Chromium

CRTs; Cathode Ray Tubes

Cu; Copper

DfE; Design for Environment

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DoE; Department of Environment

EEE; Electronic and Electrical Equipment

EMPA; Federal Laboratories for Materials Testing and Research

EOL; End-of-Life

EPR; Extended Producer Responsibility

ERP; European Recycling Platform

ETBC; Electronics Take-Back Coalition

EU; European Union

EU WEEE; European Union Waste Electronic and Electrical Equipment

eWASA; e-Waste Association of South Africa

HARL; Home Appliance Recycling Law

Hg; Mercury

HNO3; Nitric Acid

HP; Hewlett-Packard

IC; Integrated Circuit

ICT; Information Communication and Technology

In; Indium

IT; Information Technology

JICA; Japanese International Cooperation

LCD; Liquid Crystal Display

LG; Life's Good

Li; Lithium

MoEF; Ministry of Environment and Forests

MSW; Municipal Solid Waste

NGOs; Non-governmental Organizations

Ni; Nickel

OECD; Organization of Economic Cooperation and Development

PAHs; Polycyclic Aromatic Hydrocarbons

Pb; Lead

PBBs; Polybrominated Biphenyls

PBDEs; Polybrominated Diphenyl Ethers

PCB; Printed Circuit Board

PCBs; Polychlorinated Biphenyls

PCDD/Fs; Polychlorinated Dibenzo-p-dioxins Dibenzofurans

PCs; Personal Computers

Pd; Palladium

POPs; Persistent Organic Pollutants

PPP; Personal Protective Clothing

PROs; Producer Responsibility Organizations

RoHS; Removal of Hazardous Substance

Sb; Antimony

SECO; Swiss State Secretariat for Economic Affairs

S.E.N.S.; Stiftung Entsorgung Schweiz

Sn; Tin

StEP; Solving the E-waste Problem

SVTC; Silicon Valley Toxic Coalition

SWICO; Swiss Association for Information Communication and Organizational Technology

TG; Thematic Group

UEEE; Unused Electronic and Electrical Equipment

UN; United Nations

UNEP; United Nations Education Programme

US; United States

USEPA; United States Environmental Protection Agency

WEEE; Waste Electronic and Electrical Equipment

WHO; World Health Organization

VAT; Value-added Tax

Zn; Zinc

3R; Reduce, Reuse, Recycle

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Author details

Daniel Mmereki[1,2,3*], Baizhan Li[1,2,3], Andrew Baldwin[1,2] and Liu Hong[1,2,3]

*Address all correspondence to: dani.mmereki2@gmail.com

1 National Centre for International Research of Low Carbon and Green Buildings, Chongqing University, Chongqing, China

2 School of Urban Construction and Environment Engineering, Chongqing University, Chongqing, China

3 Key Laboratory of Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing, China

References

[1] Huisman J, Magalini F, Kuehr R, Maurer C, Ogilvie S, Poll J, Delgado C, Artim E, Szlezak A. Review of Directive 2002/96 on waste electrical and electronic equipment (WEEE). Bonn: United Nations University, 2007. p 377.

[2] ITU. Measuring the Information Society 2011. A report from the International Telecommunication Union. http://www.itu.int/ITU-D/ict/publications/idi/ 2011/Material/MIS_2011_without_annex_5.pdf. [Access date: 14 December 14 2014a].

[3] ITU. The world in 2011. ICT Facts and Figures. http://www.itu.int/ITU-D/ict/facts/2011/material/ICTFactsFigures2011.pdf. [Access date: 14 December 2014b].

[4] UN University. 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE). Bonn, Germany, United Nations University, 2007. Available: http://ec.europa.eu/environment/waste/weee/pdf/final_rep_unu.pdf.

[5] Schluep M, Hagelueken C, Kuehr R, Magalini F, Maurer C, Meskers. C, Mueller E, Wang F. Sustainable Innovation and Technology Transfer Industrial Sector Studies. Recycling from E-Waste to Resources. United Nations Environment Programme & United Nations University, 2009. p. 120.

[6] Chancerel P, Meskers CE, Hagelüken C, Potter VS. Assessment of precious metal flows during preprocessing of waste electrical and electronic equipment. Journal of Industrial Ecology 2009; 13(5): 791-810.

[7] Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Böni H, Schnellmann M. Global perspectives on e-waste. Environmental Impact Assessment Review 2005; 25(5): 436-458.

[8] Bigum M, Claus Petersen C, Christensen TH, Scheutz C. WEEE and portable batteries in residual household waste: Quantification and characterization of misplaced waste. Waste Management 2013; 33: 2372-2380.

[9] Ongondo FO, Williams ID, Cherrett TJ, How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste Management 2011; 31: 714-730.

[10] Wath SB, Vaidya AV, Dutt PS, Chakrabarti T. A roadmap for development of sustainable E-waste management system in India. Science of the Total Environment 2010; 409: 19-32.

[11] EU. Directive 2002/96/EC of the European parliament and the council of 27 Jan. 2003 on waste electrical and electronic equipment (WEEE)-joint declaration of the European parliament, the council and the commission relating to article 9. http://eurlex.europa. eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0096:EN:NOT2003. [Access date: 25 May 2015].

[12] BAN. The Basel Action Network (BAN), The Silicon Valley Toxics Coalition (SVTC), Toxics Link India, SCOPE (Pakistan), Greenpeace China. Exporting harm: The high-tech trashing of Asia. Seattle, WA, San Jose, CA 2002; February 25, 2002.

[13] Puckett J, Smith T. Exporting harm: The high-tech trashing of Asia. The Basel Action Network, Silicon Valley Toxics Coalition, Seattle 2002: Online at: http://www.ban.org/E- waste/technotrashfinalcomp.pdf.

[14] OECD. Extended producer responsibility; a guidance manual for governments: Organization of Economic Co-operation and Development (OECD) 2001.

[15] Sinha-Ketriwal D. The management of electronic waste: A comparative study on India and Switzerland. St. Gallen, University of St. Gallen. Master in Environmental Engineering 2004.

[16] StEP. What is e-waste? Solving the e-waste problem (StEP). http://www.step-initiative. org/initiative/what-is-e-waste.php2010. [Access date: 10 June 2015].

[17] The Economist. Recycling old computers, The Economist, 56 London; 2005. September 29, 2005.

[18] Andarani P, Goto N. Potential e-waste generated from households in Indonesia using material flow analysis. Journal of Material Cycles and Waste Management 2014; 16: 306-320.

[19] Oliveira CRD, Bernardes AM, Gerbase, AE. Collection and recycling of electronic scrap: A worldwide overview and comparison with the Brazilian situation. Waste Management 2012; 32: 1592-1610.

[20] Department of Environment. The e-waste inventory project Malaysia. Department of Environment, Malaysia 2009.

[21] UNEP. A report: Recycling from E-waste to resources, 2010. Released by United Nations Environment Programme (UNEP); 2010. February 22, 2010.

[22] Karla V. An article UNEP recognises the e-waste problem in Asia-Pacific, 2004, published on June 26, 2004. http://www.toxicslink.org/art-view.php?id=34.

[23] Kimberley M. An article E-waste in India: A Growing Industry and Environmental Threat, 2007. Published on September 10, 2007. http://www.treehugger.com/ files/2007 /10/e-waste_in_india.php.

[24] Robinson B. E-waste: An assessment of global production and environmental impacts. Science of Total Environment 2009; 408: 183-191.

[25] Shao G, Li Y, Xu X, Liu J, Wu K, Gu C. The hazard of chromium exposure to neonates in Guiyu of China. The Science of Total Environment 2008; 403(1-3): 99-104.

[26] Blass VD, Favret L, Fuji M, Mahdavi S, Miller R, Neira J. End-of-life management of cell phones in the United States. Donald Bren School of Environmental Science and Management University of California, Santa Barbara, CA 2006. [M.S. Thesis].

[27] Liu Q, Li KQ, Zhao H, Li G, Fan FY. The global challenge of electronic waste management. Environmental Science and Pollution Research 2009; 16(3)L 248-249.

[28] Chancerel P. Substance flow analysis of the recycling of small waste electrical and electronic equipment: An assessment of the recovery of gold and palladium. Papierflieger 2009.

[29] Hischier R, Wager P, Gauglhofer J. Does WEEE recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). Environmental Impact Assessment Review 2005; 25: 525-39.

[30] Manga VE, Forton OT, Read AD. Waste management in Cameroon: A new policy perspective? Resources, Conservation and Recycling 2008; 52: 592-600.

[31] Babu BR, Parande AK, Basha CA. Electrical and electronic waste: A global environmental problem. Waste Management & Research 2007; 25: 307-18.

[32] Kahhat R, Kim J, Xu M, Allenby B, Williams E, Zhang P. Exploring e-waste management systems in the United States. Resources, Conservation and Recycling 2008; 52: 955-964.

[33] UNEP. Developing integrated solid waste management plan training manual—volume 2: Assessment of current waste management system and gaps therein. United Nations Environment Programme (UNEP); 2009. http://www.unep.or.jp/ ietc/Publications/spc/ISWMPlan_Vol2.pdf.

[34] Sthiannopkao S, Wong MH. Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. Science of the Total Environment 2012; 463-464: 1147-1153.

[35] Lepawsky J. The changing geography of global trade in electronic discards: Time to rethink the problem. The Geographical Journal 2015; 181: 147-159. doi: 10.1111/geoj.12077.

[36] Gullett BK, Linak WP, Touati A, Wasson SJ, Gatica S, King CJ. Characterization of air emissions and residual ash from open burning of electronic wastes during simulated rudimentary recycling operations. Journal of Material Cycles and Waste Management 2007; 9: 69-79.

[37] Bo B, Yamamoto K. Characteristics of e-waste recycling systems in Japan and China. World Academy of Science, Engineering and Technology 2010; 62.

[38] Yu J, Williams E, Ju M, Shaoa C. Managing e-waste in China: Policies, pilot projects and alternative approaches. Resources, Conservation Recycling 2010a; 54(11): 991-999.

[39] Yu J, Williams E, Ju M, Yang Y. Forecasting global generation of obsolete personal computers. Environmental Science and Technology 2010b; 44(9): 3232-3237.

[40] Inglezakis VJ, Moustakas K. Household hazardous waste management: A review. Journal of Environmental Management 2015; 150: 310-321.

[41] Nnorom IC, Osibanjo O. Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resources, Conservation and Recycling 2008; 52: 843-58.

[42] He W, Li G, Ma X, Wang H, Huang J, Xu M, Huang C. WEEE recovery strategies and the WEEE treatment status in China. Journal of Hazardous Materials 2006; B136: 501-512.

[43] Dwivedy M, Mittal RK. An investigation into e-waste flows in India. Journal of Cleaner Production 2012; 37: 229-242. doi:10.1016/j.jclepro.2012.07.017.

[44] Kojima M, Yoshida A, Sasaki S. Difficulties in applying extended producer responsibility policies in developing countries: Case studies in e-waste recycling in China and Thailand. J Material Cycles & Waste Management 2009; 11(3): 263-269.

[45] ERP. European Recycling Platform. http://www.erp-recycling.org/. [Accessed date: 4 April 2015].

[46] Wäger PA, Hischier R, Eugster M, 2011. Environmental impacts of the Swiss collection and recovery systems for Waste Electrical and Electronic Equipment WEEE: A follow-up. Science of Total Environment 2011; 409: 1746-1756.

[47] Wagner TP. Shared responsibility for managing electronic waste: A case study of Maine, USA. Waste Management 2009; 29 3014-3021.

[48] e-Stewards. About certification. Basel Action Network; 2011. http://e-stewards.org/certification-overview/e-stewards-certification-process/. [Access date: 2 June 2015].

[49] Yoshida A, Tasaki T, Terazono A. Material flow analysis of used personal computers in Japan. Waste Management 2009; 29: 1602-1614.

[50] Araújo MG, Magrini A, Mahler CF, Bilitewski B. A model for estimation of potential generation of waste electrical and electronic equipment in Brazil. Waste Management 2012; 32: 335-342.

[51] Shumon Md. RH, Ahmed S, Islam Md. T. Electronic waste: Present status and future perspectives of sustainable management practices in Malaysia. Environmental Earth Science 2014; 72: 2239-2249.

[52] European Commission. Draft proposal for a European parliament and council directive on waste electric and electronic equipment, Brussels, 2000, Belgium; 2000. http://www. eia.org/download/eic/21/www_Final_Proposal_June_2000.htm. May 31, 2015.

[53] Khetriwal DS, Kraeuchi P, Schwaninger M. A comparison of electronic waste recycling in Switzerland and in India. Journal of Environmental Impact Assessment Reviews 2005; 25: 492-504.

[54] Khetriwal DS, Kraeuchi P, Widmer R. Producer responsibility for E-waste management: key issues for consideration — learning from the Swiss experience. Journal of Environmental Management 2009; 90(1) 153-65.

[55] Bernstad, A., la Cour Jansen, J., Aspegren, H. Property-close source separation of hazardous waste and waste electrical and electronic equipment—a Swedish case study. Waste Management 2011; 31: 536-543.

[56] Ogushi Y, Kandlikar M. Assessing extended producer responsibility laws in Japan. Environmental Science and Technology 2007; 41(13): 4502-4508.

[57] Darby L, Obara L. Household recycling behaviour and attitudes towards the disposal of small electrical and electronic equipment. Resources, Conservation and Recycling 2005; 44: 17-35.

[58] Chung S-W, Murakami-Suzuki R. A comparative study on e-waste recycling systems in Japan, South Korea, and Taiwan from the EPR perspective: Implications for developing countries. In: Kojima, M. (Ed.), Promoting 3Rs in Developing Countries: Lessons from the Japanese Experience. Institute of Developing Economics 2008; 125-145.

[59] DOWA ECO-SYSTEM CO.: International Recycling Networks for Mobile Phones in Asian Region. 2007. http://archive.basel.int/techmatters/e_wastes/Report_DOWA_PJ.pdf. [Access date: 26 May 2015].

[60] Jang YC, Kim M. Management of used & end-of-life mobile phones in Korea: A review. Resources, Conservation and Recycling 2010; 55: 11-19.

[61] Jang C-H. Waste electrical and electronic equipment (WEEE) management in Korea: Generation, collection, and recycling systems. Journal of Material Cycles and Waste Management 2010; 12: 283-294.

[62] MoEF, Guidelines for environmentally sound management of e-waste (as approved vide Ministry of Environment and Forests (MoEF) letter No. 23-23/2007-HSMD, MoEF 2007, March 12, 2008.

[63] Dwivedy M, Suchde P, Mittal RK. Modeling and assessment of e-waste take-back strategies in India. Resources, Conservation and Recycling 2015; 96: 11-18.

[64] Lee CH, Chang SL, Wang KM, Wen LC. Management of scrap computer recycling in Taiwan. Journal of Hazardous Materials 2010; 73(3): 209-220.

[65] eWASA. e-Waste Association of South Africa. http://ewasa.org/. [Access date: 4 April 2015].

[66] Atasu A, Van Wassenhove LN, Sarvary M. Efficient take-back legislation. Production, Operation Management 2009; 18(3): 243-258.

[67] Wang F, Huisman J, Meskers CEM, Schluep M, Stevels Ab, Hagelüken C. The Best-of-2-Worlds philosophy: Developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. Waste Management 2012; 1-13.

[68] Tojo N. Extended Producer Responsibility Legislation for Electrical and Electronic Equipment—Approaches in Asia and Europe 2001.

[69] Kiddee P, Naidu R, Wong MH. Electronic waste management approaches: An overview. Waste Management 2013; 33: 1237-1250.

[70] Shinkuma T, Huong NTM. The flow of e-waste material in the Asian region and a reconsideration of international trade policies on e-waste. Environmental Impact Assessment Review 2009; 29: 25-31.

[71] Kojima M. E-waste take-back system design. Paper presented at the Greater Mekong Sub-region (GMS) training workshop on building capacity to deal with the illegal shipments of e-waste and near-end-of-life electronics, Ha Noi, Vietnam 2012.

[72] Chung SS, Lau KY, Zhang C. Generation of and control measures for e-waste in Hong-Kong. Waste Management 2011; 31: 544-554.

[73] Kahhat R, Williams E. Product or waste? Importation and end-of-life processing of computers in Peru. Environmental Science and Technology 2009; 43(15): 6010-6016.

[74] Sander K, Schilling S. Transboundary shipment of waste electrical and electronic equipment/ electronic scrap-Optimization of material flows and control. UBA-FKZ 3708 93 300. Umweltbundesamt 2010. p. 118.

[75] Anderson M. What an E-waste. IEEE Spectrum 2010; 47(9): 72.

[76] Krikke J. Recycling e-Waste: the Sky Is the Limit. IT Professional 2008; 10 (1); 50-55.

[77] Tsydenova O, Bengtsson, M. Chemical hazards associated with treatment of waste electrical and electronic equipment. Waste Management 2011; 31: 45-58.

[78] Williams E, Ramzy K, Allenby B, Kavazanjian E, Xu M, Kim J. Environmental, social and economic implications of global reuse and recycling of personal computers. International Journal Environmental Science Technology 2008; 42(17): 6446-54.

[79] He W, Li G, Ma X, Wang H, Huang J, Xu M, Huang C. WEEE recovery strategies and the WEEE treatment status in China. Journal of Hazardous Materials 2006; B136: 501-512.

[80] Wong MH, Wu SC, Deng WJ, Yu XZ, Luo Q, Leung AOW. Export of toxic chemicals —a review of the case of uncontrolled electronic waste recycling. Environmental Pollution 2007; 149: 131-140.

[81] Xu X, Yang H, Chen A, Zhou Y, Wu K, Liu J, Zhang Y, Huo X. Birth outcomes related to informal e-waste recycling in Guiyu, China. Reproduction Toxicology 2012; 33: 94-98.

[82] Ha NN, Agusa T, Ramu K, Tu NPC, Murata S, Bulbule KA, Parthasaraty P, Takahashi S, Subramanian A, Tanabe S. Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere 2009; 76: 9-15.

[83] Manomaivibool P. Extended producer responsibility in a non-OECD context: The management of waste electrical and electronic equipment in India. Resources, Conservation, Recycling 2009; 53(3): 136-44.