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Global Management of Electronic Wastes: Challenges Facing Developing and Economy-in-Transition Countries

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3.1 Introduction

3.1.1 Electronic waste (E-waste): Definitions, Categories and Composition

Waste electrical and electronic equipment (WEEE), electronic waste or e-waste, electronic scrap or e-scrap, and end-of-life (EoL) electronic devices are synonyms used to describe discarded electrical or electronic devices. E-waste is composed of a variety of disposed electrical and electronic devices that can be categorized on the basis of their size (large or small), areas of application/uses (toys, consumer or household goods), and reusability/recyclability (Baldé et al., 2014). Attempts have also been made to differentiate e-waste from WEEE thus: while e-waste describes electronic goods, such as computers, television and radio sets, and mobile phones, WEEE refers to all equipment powered by electricity and, therefore, includes non-electronic goods such as refrigerators, air conditioners, and washing machines (Robinson, 2009). Finlay (2005) gave a standard definition of e-waste to include all end-of-life (EoL) electronic products, components and peripherals, such as computers, cell phones, fax machines, photocopiers, radio sets and TV. Widmer et al.

Metal Sustainability: Global Challenges, Consequences, and Prospects, First Edition. Edited by Reed M. Izatt.

Table 1 *Selected definitions of electronic waste or E-waste*

Definitions	References
"Electrical or electronic equipment which is waste including all components, sub-assemblies and consumables, which are part of the product at the time of discarding." "Directive 75/442/EEC, Article 1(a) defines waste as any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force."	(EU, 2003)
"E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their owners."	BAN/SVTC, 2002
"Any appliances using an electric power supply that has reached its end-of-life"	OECD, 2001
"An electrically powered appliance that no longer satisfies the current owner for its original purpose."	Widmer et al., 2005
E-waste or WEEE: "Electrical and electronic equipment that is no longer suitable for use or that the last owner has discarded".	SBC, 2011
"E-waste is a term used to cover all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of reuse"	StEP, 2012
E-waste means: "waste electrical electronic equipment (WEEE) including old, end-of-life (EoL) or discarded electrical/electronic appliances that use electricity".	Osibanjo, 2009a

(2005), however, claim that there is, yet, no standard definition or general agreement as to whether the term e-waste applies to resale, reuse, and refurbishing industries or to specific products that cannot be used for their intended purpose. Some of the different definitions of e-waste in literature are summarized in Table 1. A common understanding can be inferred from these definitions that e-waste and WEEE refer to electrical and electronic gadgets that are at their end of life, obsolete or discarded by their original owners.

E-waste is considered hazardous waste under the List A1180 of Annex VIII of the Basel Convention on the control of trans-boundary movements of hazardous wastes and their disposal (SBC, 2011). A decision tree to determine whether used electronic equipment is waste to be controlled under the Basel Convention or not is shown in Figure 1. The fact that the electrical and electronic equipment (EEE) imported into developing countries is usually an admixture of EEE, used EEE, near end-of-life EEE and WEEE make such devices difficult to control under the Basel Convention Control (Osibanjo, 2009b).

3.1.2 Typology and Categories of E-waste

According to the European Union WEEE directive *2002/96/EC* (EU, 2003), which is widely adopted internationally, the term electronic waste (e-waste) or waste electrical and electronic equipment (WEEE) refers to unwanted EEE that are obsolete, at the end of their lives or have been discarded by their original users. The typology of the 10 WEEE categories according to the EU WEEE Directive is listed in Table 2.

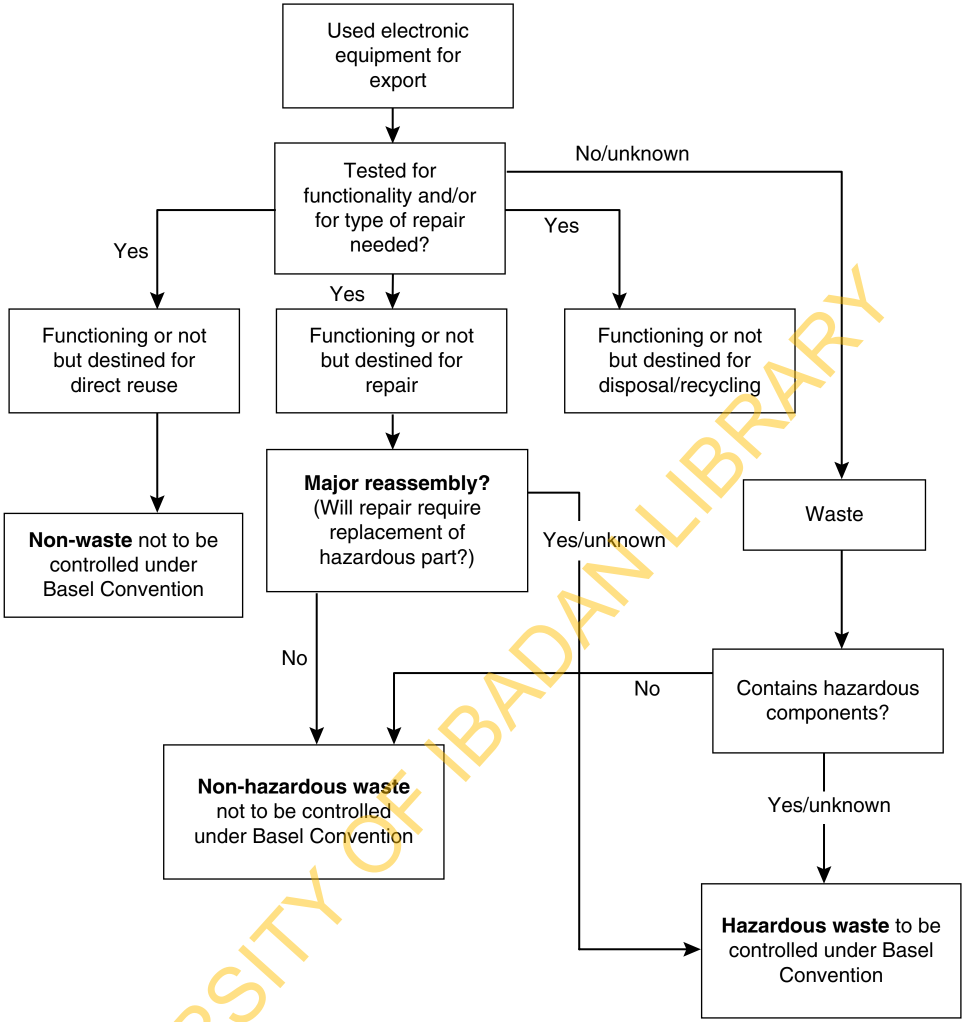

Figure 1 *Decision tree to determine whether used electronic equipment is a waste to be controlled under the Basel Convention or not. Source: Puckett et al. (2005)*

E-waste has been reported to comprise large household electrical appliances, such as fridges, air conditioners, washing machines, and microwave ovens as the largest proportion (about 50%) of e-waste, followed by information and communications technology (ICT) equipment (about 30%), and consumer electronics such as fluorescent light bulbs, electronic products, television sets and stereo equipment (about 10%) (ILO, 2012). Balde *et al.* (2014) recently classified six new categories of EEE and WEEE (Table 3) based on original function, weight, size, and material composition of each category of device, by streamlining the 10 categories in EU WEEE directive (Table 2) into six categories. Table 4 provides a list of common items of e-waste (Robinson, 2009).

Table 2 *Ten Categories of E-waste according to the EU WEEE Directive 2002/96/EC. Source: (UNEP 2007)*

	Category	Typical Examples
1	Large Household Appliances	Refrigerators, freezers, washing machines, clothes dryers, microwaves, heating appliances, radiators, fanning/ exhaust ventilation/conditioning equipment
2	Small Household Appliances	Vacuum cleaners, other cleaners, sewing/knitting/ weaving textile appliances, toasters, fryers, pressing irons, grinders, opening/sealing/packaging appliances, knives, hair cutting/drying/shaving devices, clocks, watches
3	IT and Telecommunication Equipment	Mainframes, microcomputers, printers, PCs (desktop, notebooks, laptops), photocopiers, typewriters, fax/telex equipment, telephones
4	Consumer Equipment	Radio and TV sets, video cameras/decoders, hi-fi recorder, audio amplifiers, musical instruments
5	Lighting Equipment	Bulbs for fluorescent lamps, low-pressure sodium lamps
6	Electrical and Electronic Tools (excluding large-scale industrial tools)	Drills, saws, sewing machines, turning/milling/sanding/ sawing/cutting/shearing/drilling/punching/folding/bending equipment, riveting/nailing/screwing tools, welding/ soldering tools, spraying/spreading/dispersing tools,
7	Toys, Leisure and Sports Equipment	Electric trains, car racing sets, video games, sports equipment, coin slot machines, biking/diving/running/ rowing computers
8	Medical Devices	Devices for radiotherapy/cardiology/dialysis, ventilators, analyzers, freezers, fertilization tests, detecting/ preventing/monitoring/treating/alleviating illness, injury or disability
9	Monitoring and Control Instruments	Smoke detectors, heating regulators, thermostats, measuring/weighing/adjusting appliances for household or laboratory use, other industrial monitoring and control instruments
10	Automatic Dispensers	For hot drinks, hot or cold bottles/cans, solid products, money, and all kinds of products

Table 3 *Six categories of E-waste according to Balde et al. (2014). Source: Balde et.al (2014)*

	Category	Typical Examples
1	Temperature exchange cooling and freezing equipment	Refrigerators, freezers, air conditioners, heat pumps
2	Screens, monitors.	Televisions, monitors, laptops, notebooks, tablets
3	Lamps	Straight lamps, LED lamps
4	Large Equipment	Washing machines, clothes dryers, dish washing machines, electric stoves, large printing machines, copying equipment and photovoltaic panels.
5	Small Equipment	Vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets
6	Small IT and telecommunication equipment	Mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones

Table 4 Some toxic and hazardous components of e-waste

Item	Hazardous Components
Cathode ray tube	Lead, antimony, mercury, phosphorus
Liquid crystal display	Mercury
Circuit board	Lead, beryllium, antimony, brominated flame retardants (BFR)
Fluorescent lamp	Mercury, phosphorus, flame retardants
Cooling systems	Ozone-depleting substance (ODS)
Plastic	BFRs, phthalate plasticizer
Insulation	Ozone-depleting substances in foam, asbestos, refractory ceramic fibre
Rubber	Phthalate plasticizer, BFRs, lead
Electrical Wiring	Phthalate plasticizer, BFRs
Batteries	Lead, lithium, cadmium, mercury

Source: UNEP, 2007; MoEF, 2008.

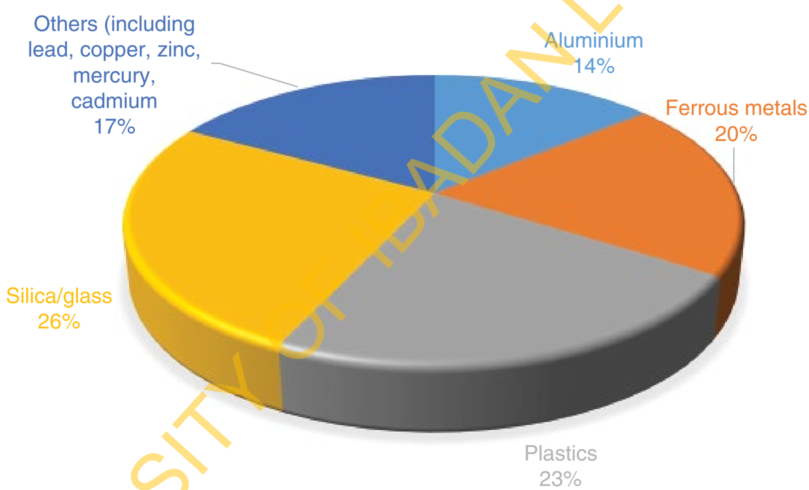

Figure 2 Material composition of waste personal computer

3.2 E-waste Composition

Electrical and electronic equipment (EEE) and WEEE are made of components/materials that are highly valuable as well as those that are toxic and hazardous to both man and the environment. Generally electronic products and the e-waste arising from them consist of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete and ceramics, rubber and other items. The relative composition of the components depends on product type and production technology. Iron and steel constitute about 50% of e-waste, followed by plastics (21%), non-ferrous metals (13%), and other constituents (UNEP, 2007). The material composition of a personal computer (PC) shown in Figure 2 indicates that ferrous metal and aluminum constitute 20% and 14%, respectively. In addition, there are other metals

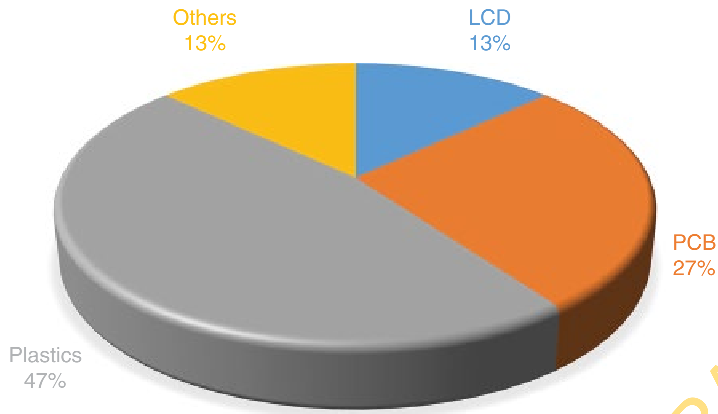

Figure 3 *Material composition of waste mobile phone. (See insert for color representation of the figure.)*

such as copper, lead, cadmium, mercury and zinc, which together make up 17% of the PC. Figure 3 indicates the material composition of a mobile phone as comprising plastics (47%), printed circuit board (27%), liquid crystal display (LCD) (13%) and others including metals (13%) (Babayemi et al., 2014).

In developing countries like Nigeria, erratic electricity power supply is a major challenge to sustainable socioeconomic and industrial development. Rechargeable and non-rechargeable electric torches and rechargeable lamps serve as alternatives that have been used extensively for domestic lighting sources, as they are readily available, affordable and portable, compared to diesel or gasoline-powered generator engines. Hitherto, local and international attention in scientific literature to have focused mainly on e-wastes from information and communications equipment and from consumer electronics (categories 3 and 4 of EU WEEE directive), such as mobile phones, computers, TVs and large household appliances, as the main contributors to electronic waste. But domestically generated WEEE also constitute a significant portion of domestic e-waste and should not be ignored, especially in developing countries. Figure 4 shows percentage composition of spent rechargeable lamps with the following composition: battery (50%); plastic (40%); glass (5%), PCBs (4%) and metal (<1%) respectively, while Figures 5 and 6 indicate pictorial samples of waste rechargeable electric lamps (WRELs) and samples of waste rechargeable electric torches (WRETs) and their batteries imported into Nigeria, mainly from China (Ogundiran et al., 2014a, 2014b, 2015).

There is a paucity of information about the toxicity and environmental fate of some of the over 1,000 assorted chemicals identified in e-waste streams. This is largely a result of rapidly changing manufacturing processes, the chemicals used, and increasing public awareness of the harm to humans and the environment from environmental releases of these chemicals which enhance regulatory control in some regions and countries.

Electrical and electronic products and e-waste often contain several persistent, bioaccumulative and toxic substances, including heavy metals such as lead, nickel, chromium and mercury (UNEP, 2011), and persistent organic pollutants (POPs), such as polychlorinated

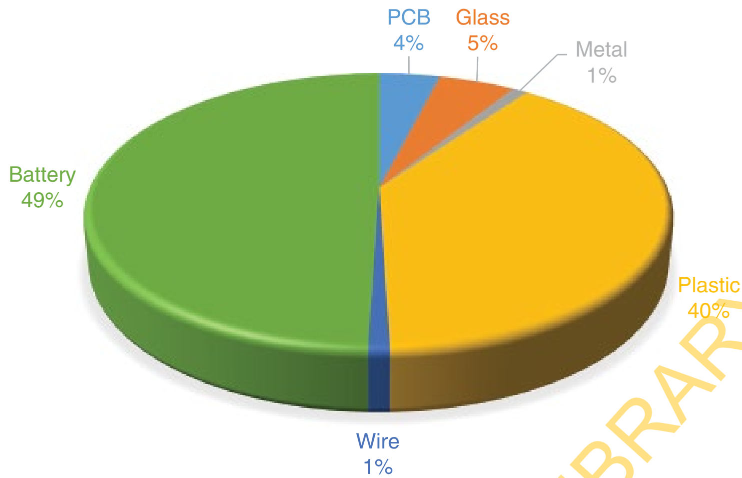

Figure 4 *Mean percentage composition of spent rechargeable lamps*

biphenyls (PCBs) and brominated flame retardants (BFRs) (Sindiku et al., 2014). Presented in Table 4 are some components of WEEE and their potentially hazardous and toxic contents. For instance, the cathode ray tube (CRT) of a TV or computer monitor could contain as much as 4 kg of lead (Nnorom *et al.,* 2011).

CRTs also contain antimony, phosphorus, etc. in some proportions, while circuit boards in different electrical and electronic products contain lead, beryllium, antimony and brominated flame retardants (BFRs). Other toxic substances contained in various electronic items include selenium, antimony trioxide, cadmium, cobalt, manganese, bromine and barium, amongst many others. Table 5 indicates that valuable metals are also present in the printed circuit boards of selected electronic products.

There is also increasing international concern about the large amounts of epoxy resins, fibre glass, PVC (polyvinyl chlorides), thermosetting plastics, lead, tin, copper, silicon, beryllium, carbon, iron and aluminium, and the trace amounts of germanium, tantalum, vanadium, terbium, gold, titanium, ruthenium, palladium, manganese, bismuth, niobium, rhodium, platinum, carbon, cerium, antimony, arsenic, barium, boron, cobalt, europium, gallium, indium, lithium, manganese, nickel, palladium, ruthenium, selenium, silver, tantalum, molybdenum, thorium and yttrium present in e-waste (Chi, 2011).

While functional and in use, these potentially toxic and hazardous components of EEE and e-waste portend little or no danger to users. However, the negative environmental effects from the toxic materials content of e-wastes are most visible in the end-of-life (EoL) stage (Nnorom and Osibanjo, 2009a, b; Nnorom et al., 2010). The exponential growth in consumer waste in recent years has started to threaten the environment and is posing significant challenge to waste management experts. The magnitude of the problem is exemplified by the fact that in the decade between 1994 and 2003, about 500 million personal computers containing approximately 718,000 tonnes of lead, 1,363 tonnes of cadmium and 287 tonnes of mercury, reached their end-of-life (Smith et al., 2006) and the heavy metals content will be released into the environment if not properly managed.

Figure 5 *Samples of waste rechargeable electric torches (WRETs) and waste non-rechargeable electric torches (WNETs)*

Figure 6 *Samples of waste rechargeable electric lamps (WRELs) and their batteries*

Table 5 *Contents of selected valuable metals in the printed circuit boards of selected electronic products*

Product	Valuable metals contained in products
TV (CRT monitor)	gold, silver, copper, platinum, antimony, nickel, yttrium, neodymium, iron, and aluminium
Washing machine, air conditioner, refrigerator	gold, silver, copper, platinum, antimony, iron, and aluminium
TV (LCD, plasma)	gold, silver, platinum, antimony, indium, yttrium, iron, aluminium

3.3 E-waste Generation

Over the years, the rapid growth in ICT (an umbrella term that includes any communication device or application: radio, TV, mobile phones, computer and network hardware and software, satellite systems, etc.) has led to phenomenal improvement in the capacity and features of electronics but simultaneously to a drastic decrease in the product's lifetime. In fact, the growth of the electronics sector and the rapid changes in technology mean that more consumers are replacing more equipment more often than ever before. One reason for the increasing generation of e-waste is the constant availability of newer technologies and designs and an increasingly early obsolescence. For example, the average lifespan of a new-model computer has decreased from 4.5 years in 1992 to an estimated 2 years in 2005 and is continuing to decrease (Widmer et al., 2005). Electronic waste is generated by three major sectors: individuals and small businesses; large businesses, institutions, and governments; and, original equipment manufacturers (OEMs). There are a number of reasons for a product reaching its end-of-life. These reasons include technical obsolescence (the product itself is worn out and no longer functions properly); economic obsolescence (new products in the market are more economical in terms of cost); feature obsolescence (new products have come onto the market that offer more or better features), and aesthetic obsolescence (new products in the market have a nicer look or more fashionable design from the point of view of the consumer) (Osibanjo and Nnorom, 2008; Nnorom et al., 2009).

3.3.1 Estimated Global Quantities of E-waste Generated

The last 2–3 decades have witnessed a tremendous upsurge in the global generation of e-waste, with estimated global annual quantities in 2006 reaching 40 to 50 million metric tons (UNEP, 2006; Schluep et al., 2009; Sepulveda et al., 2010; StEP, 2012). Estimates by Cobbing (2008) also revealed that by 2015, personal computers, mobile phones and television sets would have contributed an additional 9.8 million tons to the global e-waste stream. Estimates of e-waste generation in different countries and regions across the globe based on available literature/data have been reported and are indicated in Table 6 though measurement of actual quantities in a reliable manner remains a challenge. The order of e-waste generation based on Table 6 is Asia > North America > Europe > Africa > Latin America > Oceania. Nonetheless, Nigeria generates the highest e-waste annually in Africa of about 1.2 million tons (Table 6; SBC, 2011).

Table 6 *Global quantities of e-waste generated by continent*

Continent	Country	Quantities (1000 tons/yr)	Per capita (Kg/person)	Year of generation
Europe	Germany	1,100	13.3	2005[a]
	UK	940	15.8	2003[a]
	Switzerland	66.04	9.0	2003[a]
Asia	China	3, 620[b]	2.6[c]	2011[b,c]
	India	439	0.4	2007[a]
	Japan	860	6.7	2005[a]
Africa	Nigeria	1,200	7.1	2011[d,e]
	South Africa	59.65	1.2	2007[a]
	Ghana	179	41.0	2011[d,e]
	Cote d'Ivoire	15	4.8	2011[d,e]
	Benin	9.7	6.32	2011[d,e]
	Kenya	7.35	0.2	2007[a]
North America	USA	2,250	7.5	2007[a]
	Canada	86	2.7	2007[a]
Latin America	Brazil	709	3.77	2008[f]
	Mexico	47.5	0.44	2006[f]
	Argentina	20	0.49	2007[f]
	Colombia	7.4	0.17	2007[f]
	Peru	7.3	0.26	2007[f]
	Chile	7.0	0.42	2008[f]
Oceania	Australia	130	1.4	2008[g]

Agamuthu and Herat, 2012[a]; CHEARI, 2012[b]; Wang et al., 2013[c]; Ogungbuyi et al., 2011[d]; SBC 2011[e]; Araujo et al., 2012[f]; Davis and Herat, 2010[g]

A more recent estimate of global e-waste generation has been put at about 41.8 million tons (Mt) (Balde et al., 2014). Asia generated most of the e-waste, to the tune of 16 Mt in 2014, with 3.7 kg per capita. The highest per-capita e-waste quantity (15.6 kg/per capita) was generated in Europe. The whole region (including Russia) generated 11.6 Mt. The lowest quantity of e-waste was generated in Oceania and was 0.6 Mt, but the per-capita generation was nearly as high as Europe's (15.2 kg per capita). The lowest amount of e-waste per capita was generated in Africa, where only 1.7 kg/capita was generated in 2014. The whole of African continent generated 1.9 Mt of e-waste. The Americas generated 11.7 Mt of e-waste (7.9 Mt for North America, 1.1 Mt for Central America, and 2.7 Mt for South America), which represented 12.2 kg per capita, and comprised 1.0 Mt of lamps, 3.0 Mt of small IT, 6.3 Mt of screens and monitors, 7.0 Mt of temperature-exchange equipment (cooling and freezing equipment), 11.8 Mt of large equipment, e.g. washing machines, large printing machines, etc, and 12.8 Mt of small equipment, e.g. vacuum cleaners, microwaves etc. Thus small equipment (30.6%) and large equipment (28.2%) together represent about 60% of total e-waste generated globally, while small IT (7.2%), e.g. mobile phones, personal computers, and screens and monitors (15.1%), e.g. TVs and monitors, together represent about (22.3%) of global e-waste generated in 2014.

The amount of e-waste generated is expected to grow to 49.8 Mt in 2018, with an annual growth rate of 4 to 5 per cent, making it the fastest-growing waste stream in the world. Table 7 shows common WEEE items and their typical life span. There is speculation

Table 7 *Characteristics of some common waste electrical and electronic equipment (WEEE) items. Source: Robinson, (2009)*

Item	Weight of item (kg)	Typical lifespan (years)	References
Computer	25	3	Betts, 2008b
Facsimile machine	3	5	Robinson, 2009
Mobile telephone	0.1	2	Cobbing, 2008
Electronic games	3	5	Cobbing, 2008
Television	30	5	Li et al., 2009
Radio	2	10	Cobbing, 2008
Photocopier	60	8	Robinson, 2009
Video and DVD player	5	5	Cobbing, 2008
High-fidelity system	10	10	Cobbing, 2008

that developing and economy-in-transition countries may generate more e-waste than developed countries by 2020. Specifically, it is foreseen that in 2030 developing countries will be discarding 400–700 million obsolete personal computers per year, compared to 200 million–300 million in developed countries.

It can be affirmed that the exponential increase and near-tsunami global generation of e-waste is due to a number of factors, such as increasing market penetration of e-products in developing countries and improving economies in transition countries (CEIT), implementation of product "take-back" schemes in developed countries, and a pervading high product obsolescence rate (UNEP, 2007; Nnorom and Osibanjo, 2008), as well as a decrease in prices enhancing affordability by the relatively poor and the growth in internet use.

3.4 Problems with E-waste

E-waste represents the dark side of the information communication technology (ICT) revolution that has transformed modern living, international business, global governance, communication, entertainment, transport, education, and health care with fast communication gadgets, such as personal computers and mobile phones (Schluep et al., 2012). E-waste contains about 60 elements in the periodic table, including hazardous substances as well as scarce and valuable resource materials. E-waste generation and its environmentally sound management represent no doubt one of the foremost environmental challenges of the 21st century. It is a globalized problem affecting both developed and developing countries. The developed countries generate most of the e-waste in uncontrollable quantities and externalize the problem by shipping electrical and electronic devices as second hand or end-of-life electronic equipment into developing and economy-in-transition countries (CEIT), which lack the infrastructure and resources for environmentally sound management of e-waste, with risk to human health (Table 8) and the environment, under the guise of bridging the so-called digital divide (Osibanjo and Nnorom, 2007). In appreciating the relevance of ICT to the achievement of sustainable development and millennium development goals (MDGs), as well as bridging the digital divide, UN Secretary-General Ban Ki-Moon encouraged member states to bridge the digital divide by turning "the digital divide into digital opportunity" (Jhin, 2007).

Table 8 *Potential adverse health effects of toxic components of e-waste on humans*

Toxin	Typical Sources	Effects on Humans
Mercury	Fluorescent lamps, LCD monitor, switches, flat panel screens	Impairment of neurological development in foetuses and small children, tremors, changes in emotions, cognition, motor function, insomnia, headaches, changes in nervous response, kidney effects, respiratory failures, death
Lead	CRT of TV, computer monitor, circuit boards	Probable human carcinogen, damage to brain and nervous systems, slows growth in children, hearing problems, blindness, diarrhoea, cognition, behavioural changes (e.g. delinquency), and physical disorder.
Chromium	Untreated and galvanized steel plates, decoration or hardener for steel housings	Asthmatic bronchitis, skin irritation, ulceration, respiratory irritation, perforated eardrums, kidney damage, liver damage, pulmonary congestion, oedema, epigastric pain, erosion and discolouration of the teeth, motor function
BFR	Plastic casings, circuit boards	May increase cancer risk to digestive and lymph systems, endocrine disorder
Cadmium	Light-sensitive resistors, as corrosion retardant, Ni-Cd battery	Inhalation due to proximity to hazardous dump can cause severe damage to the lungs, kidney, cognition

Source**:** UNEP, 2007; MoEF, 2008; Pinto, 2008; Osuagwu, 2010; Chen et al., 2007.

In the past two decades e-wastes have garnered significant interest among policymakers and waste-management experts as a problem of crisis proportions in virtually all countries because they are a waste stream with the following unique combination of problematic characteristics (Balde et al., 2014):

- High volumes – High volumes are generated due to the rapid obsolescence of gadgets combined with the high demand for new technology (BAN, 2011).
- Toxic design – E-waste is classified as hazardous waste (SBC, 2011; Tsydenova and Bengtsson, 2011) having adverse health and environmental implications. Approximately 40 per cent of the heavy metals found in landfills come from electronic waste (Montrose, 2011).
- Poor design and complexity – E-waste imposes many challenges to the recycling industry (Smith et al., 2006) as it contains many different materials that are mixed, bolted, screwed, snapped, glued or soldered together. Toxic materials are attached to non-toxic materials, which makes separation of materials for reclamation difficult. Hence, responsible recycling requires intensive labour and/or sophisticated and costly technologies that safely separate materials (BAN, 2011).
- Recycled materials compete unfavourably in some circumstances with virgin materials due to variations in composition and contamination. For instance, effective reuse of recycled cathode ray-tube glass (CRTs used in TVs and monitors) is hampered by uncertainty on the composition of recycled glass as well as possible contamination with lead.
- They contain valuable scarce materials such as gold and palladium that are not easily recoverably by simple techniques, as well as specific products of concern: CRTs, flat screen, batteries, CFCs/fridges

- Labour issues: These include occupational exposure, informal sector domination causing health and environmental problems, lack of labour standards and rights.
- Financial incentives: There is a high cost to reverse logistics; hence in general, there is not enough value in most e-waste to cover the costs of managing it in a responsible way. However, in line with extended producer responsibility (EPR) policies, new opportunities can be realized with the rise in the price of many of the materials in electronics, such as gold and copper (Widmer et al., 2005). Furthermore, with rising e-waste quantities, formal recyclers are increasingly entering the e-waste recycling sector (Raghupathy et al., 2010).
- Environmentally unsound recycling practices are adopted in developing countries.
- Lack of regulation: Many nations either lack adequate regulations applying to this relatively new waste stream, or lack effective enforcement of new e-waste regulations (BAN, 2011).

3.5 E-waste Management Challenges Facing Developing Countries

3.5.1 Introduction

Increasing consumer demand, arising from population explosion, for electrical and electronic devices in developing countries is fuelling the exponential and sometimes uncontrollable generation of e-waste globally. Developing countries have increased their share of the world's total number of internet users from 44% in 2006, to 62% in 2011. Today, internet users in China represent almost 25% of the world's total internet users (ITU, 2012). Thus it is foreseen that by 2030, there will be a reversal of the present trend and developing countries would generate significantly more e-waste than developed countries.

The major global issues facing e-waste management in the 21st century hinge on rising e-waste quantities as a result of short lifespan of electrical and electronic equipment (EEE), poor feedstock collection of e-waste, high cost of/crude resource recovery technologies, poor product design, poor regulatory and enforcement frameworks and ethical issues involving externalisation of risks. Most often, illegal, trans-boundary movement of e-waste from the developed countries to the poorer developing countries occur regularly (Figure 7). The regulatory framework and the capacity for the prevention and control of trans-boundary movement of used and end-of-life electronic products are weak and grossly inadequate in developing countries. Although most of the latter have ratified the Basel Convention, which forbids the dumping of e-waste from developed countries in developing countries and CIET, it is generally yet to be reflected in national laws.

E-waste poses a sweet-sour situation in developing countries. The hazardous constituents in e-waste are harmful to human health and the environment, which raises human exposure concerns in developing and economy-in-transition countries because of crude processing/treatment technologies employed, lack of human health safeguards, and environmental control regulations. Yet the precious metals in e-waste, such as gold and silver, provide entrepreneurship, employment, and poverty alleviation opportunities for the informal sector that dominates the e-waste recycling business. For example, experts estimate that recycling 1 million mobile phones can recover about 24 kg (50 lb) of gold, 250 kg (550 lb) of silver, 9 kg (20 lb) of palladium, and more than 9,000 kg (20,000 lb) of copper.

Thus there is a compelling need to adopt innovative policies and approaches in e-waste management. We need to modernize the 20th-century thinking about waste management as

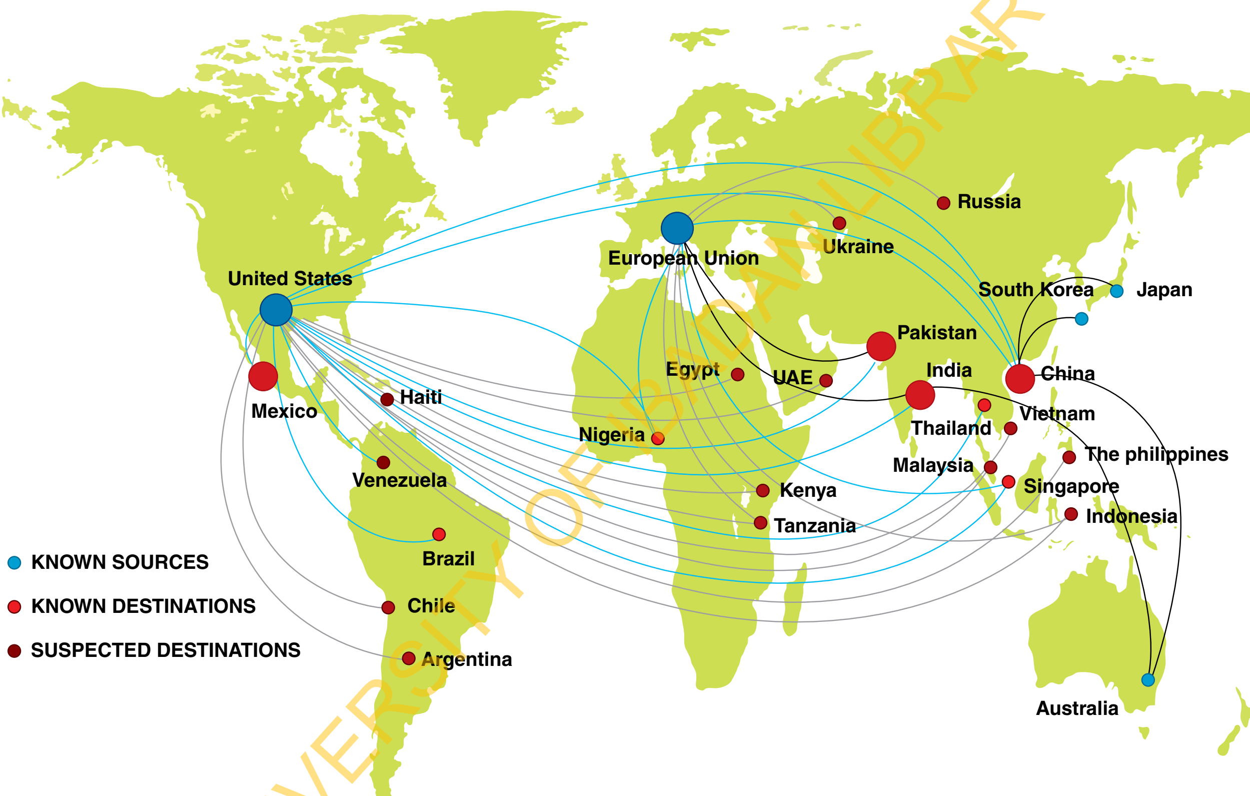

Figure 7 *E-waste flows to developing countries. (See insert for color representation of the figure.)*

"*How do we get rid of our waste efficiently with minimum damage to public health and the environment?*" to 21st-century thinking of resource management, "*How do we handle our discarded resources in ways which do not deprive future generations of some, if not all, of their value?*" This is consistent with the Basel Convention 10th conference of the parties (COP 10) Cartagena Declaration in 2010, which called for waste to be recognized as a secondary resource rather than material to be thrown away; as well as the Rio+20 outcome document "The Future We Want", which promotes transition to a "Green Economy" including waste minimization and waste utilization.

Waste generation occurs along the supply chain during various processing activities in the life cycle of electronic products (Figure 8). The major challenges associated with e-waste management in developing countries are discussed below.

3.5.2 Poor Feedstock Collection Strategies

Collection of e-waste in the developed countries is organized, though the strategies vary from country to country. In many cases there are collection points either provided by government or original equipment manufacturers (OEMs) where end-of-life (EoL) EEE or e-waste is dropped for further treatment or disposal. In some countries like Japan, consumers pay some disposal fees prior to dropping (Ogushu and Kandlikar, 2007). In most developing countries e-waste is still co-disposed with other municipal wastes, making sorting practically impossible. In a typical developing country like Nigeria, most e-wastes are collected from either refurbishers'/repairers' workshops by the informal sector or mined by scavengers (otherwise called urban miners) from dumpsites after co-disposal with other municipal wastes. This attitude in developing countries could be born primarily from lack of awareness and ignorance on the harmful effects of improper disposal of e-waste, absence of "government will" on "take-back" incentives and lack of collection centres. These deficiencies present a huge socioeconomic

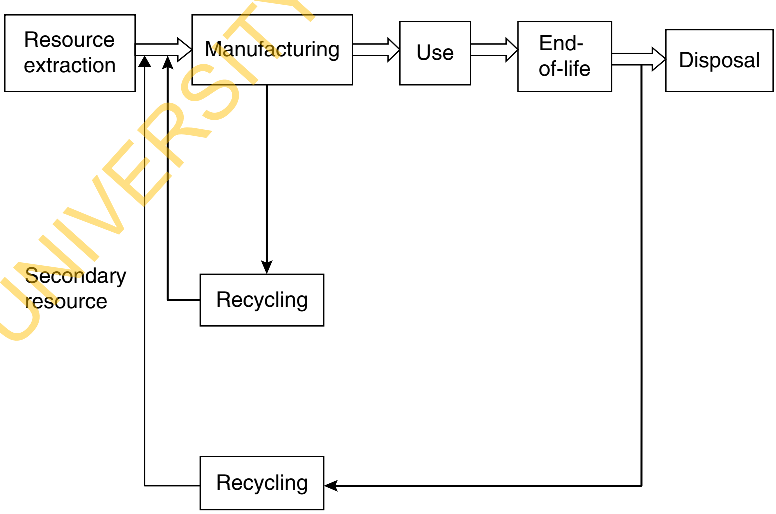

Figure 8 *Life cycle of electronic equipment. Source: Adapted from Hoang, (2009)*

challenge involving gender and child labour issues (Osibanjo, 2015), as women and children, who are more vulnerable to the deleterious effects of exposure to hazardous substances from improper e-waste management, feature prominently in e-waste collection from dumpsites.

3.5.3 Lack of State-of-the-Art Technologies to Recover Resources from E-Waste

Conventionally, e-waste after collection is sorted into different components like CRT glass, printed wiring board (PWB), plastics and others (including metals and ceramic components, etc). The flow diagram in Figure 9 depicts the major components that are disassembled from typical WEEEs and the available management methods.

The e-waste component shown in Figure 3 that is of greatest economic importance to the recycler is the PWB because of a variety of precious metals that are found glued, bolted and smeared within the board. CRT glass is the most challenging component of e-waste to manage globally, and a great percentage of this waste category is still landfilled (Kang and Schoenung, 2005; Manhart et al., 2013). The two most popular methods employed by the formal recyclers (mainly in developed countries) to recover precious metals from PWBs are pyrometallurgy and hydrometallurgy. Debates are ongoing on which method is better. Other methods that are used in the poor developing countries where the expensive methods are grossly lacking are uncontrolled open burning and backyard acid leaching. Table 9 describes each method.

Table 9 shows that the so-called high-tech methods, pyrometallurgy and hydrometallurgy have environmental and health concerns, but there are remedies in place to reduce these issues to the barest minimum. Open burning and backyard acid leaching methods are carried out by poor and uneducated people in the developing countries. These activities have deleterious effects on both the environment and human health.

3.5.4 Lack of Specific E-Waste Regulations and Enforcement in Developing Countries

E-waste-specific regulations in most developing countries are generally lacking and where they exist they are still in draft forms (in countries such as Ghana and Kenya). Where regulations exist, they are weakly enforced. Nigeria is the only African country with a National E-waste Regulation, enacted in 2011. The regulation is anchored on the 5R ('Reduce, Repair, Recover, Recycle and Re-use') principle as the primary drivers including all the categories and lists of WEEE (Ogungbuyi et al., 2012). In South Africa and many other developing countries, only generalized waste management regulations exist and there are still no e-waste-specific regulations (ATE, 2012). In China, where specific e-waste regulations have come into force, there is still a huge gap between the estimated generated quantities and the quantities actually collected by government-approved vendors (Wang et al., 2013). Because of this laxity in regulations and enforcement, the informal sector, which lacks the capacity to handle e-waste in an environmentally sound manner, is still having a field day. Therefore, the management of the increasing volumes of e-waste effectively and efficiently, in terms of resource recovery and minimal environmental impact, is still a very difficult challenge (Sinha-Khetriwal et al., 2005).

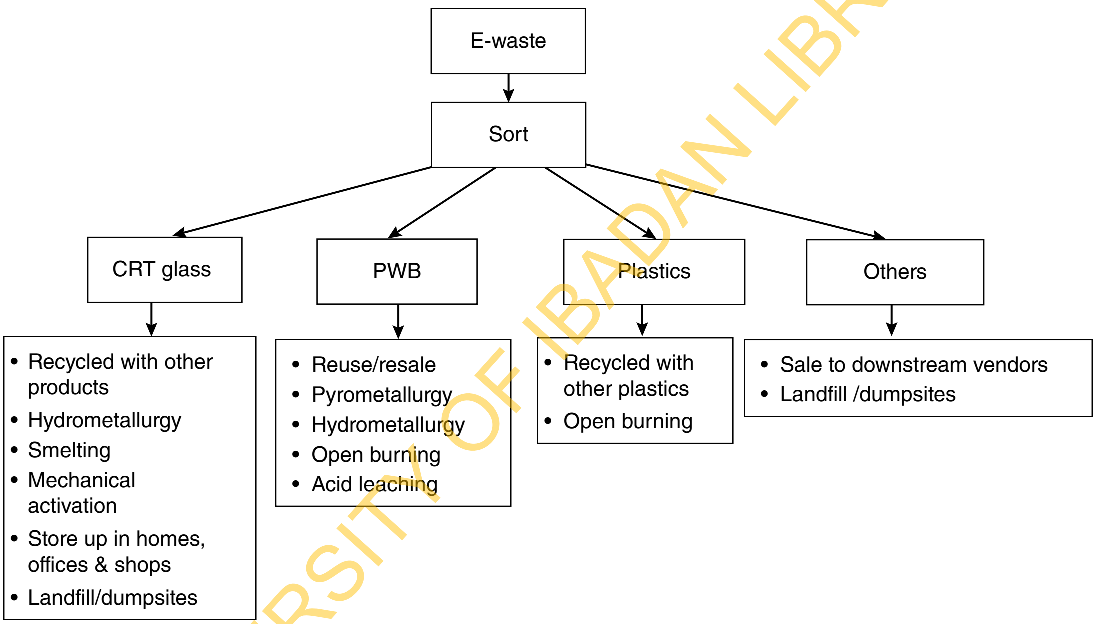

Figure 9 *Flow diagram of major components of E-waste and available management methods*

Table 9 *Major available technologies used to recover metals from e-waste*

Parameter	Pyrometallurgy	Hydrometallurgy	Open burning	Backyard acid leaching
Principle	Smelting of e-waste in furnace at high temperature to recover precious metals	Leaching of e-waste with different chemicals in controlled environment to recover precious metals	Open burning of e-waste cable to recover Cu	Soaking of e-waste in uncontrolled environment in different acid solutions to recover precious metals
Highlights of operation	• High cost of energy required to generate heat • Full capacity of furnace before processing • High cost of scrubbing system • Achieves reduced volumes through burning in controlled environment • High recovery efficiency of precious metals • No recovery of plastics and other useful non-metals	• Less energy as no heat is required • Any quantity can be processed • Uses mainly particulate and chemical scrubbing system • High volumes must be dealt with • Recovery of precious metals not as efficient as in pyro. • Plastics could be reused or recycled	• Open burning of cables to recover Cu • Burning of plastics to reduce volumes • No protection of nose • Practiced in developing and transitioning countries	• Backyard leaching with substandard tools • Low recovery and highly impure precious metals obtained • No protection of nose and hands • Practiced in developing and transitory countries
Environmental/ occupational &. health concerns	• High particulate and gaseous emissions • Loss of volatile toxic metals • Release of dioxins and furans • Generates toxic ash/slag	• Release of toxic HCN, HCl and Cl_2 gases • Generates wastewater and toxic sludge • Generates dust from crushing	• Release of dioxins and furans through burning to air, water and soil • Threat to occupational health	• Release of acid fumes • Release of acid water loaded with toxic metals like Pb on soil and water bodies • Occupational.exposure to acid fumes and toxic metals
Remedies	• Installation of particulate and wet electrostatic precipitators and chemical scrubbing system • Use of safety clothing and equipment • Installation of other pollution control equipment	• Installation of particulate and chemical scrubbing system • Use of safety clothing and equipment • Installation of other pollution control equipment	None in place	None in place

3.6 Environmental and Health Impacts of E-Waste Management in Developing Countries

E-waste has profound potential to cause damage both to the environment and to human health as the hazardous substances in e-waste may be released or leached into the environment in landfills, with potential human exposure to these pollutants during e-waste processing. This occurs during treatment processes for recyclable materials comprising plastics, glass and precious metals like gold, palladium, platinum, silver and copper. There are emerging environmental and health issues arising from e-waste management, especially in the developing countries.

3.6.1 Environmental Impacts of E-Waste

The commonest e-waste management methods in the developing countries are undertaken in the informal sector and include crude dismantling with hammers, uncontrolled open burning of cables to recover copper wire, residues of e-waste repairs and refurbishment activities, dumping on open land/spaces, and co-disposal with municipal waste on dumpsites. These methods may result in emission of persistent organic pollutants such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) (Sindiku et al., 2014), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs) (Sindiku et al., 2014) and polybrominated biphenyls (PBBs), as well as hazardous heavy metals such as Pb, Cd, Cr, Hg, and As (Babayemi et al., 2014). The methods of e-waste treatments in the developing countries encourage contamination of environmental media (air, soil, water), with consequent bioaccumulation in plants and biological organisms. The environmental impacts of e-wastes as reported from some developing countries are presented in Table 10.

3.6.2 Health Impacts of E-Waste

Resolution II/4 on emerging policy issues adopted by the International Conference on Chemicals Management of the Strategic Approach to International Chemicals management at its second session, held in Geneva in May 2009, included the adoption of hazardous substances within the lifecycle of electrical and electronic products as an emerging environmental policy issue. The contaminants released into the environment through e-wastes have been linked with arrays of health problems including endocrine disruption, cancer, liver and DNA damage, behavioural changes and developmental problems. Humans are exposed to health effects of e-waste through dermal contact, inhalation of burning smoke/dust and dietary intake through contaminated water and food (Song and Li, 2015).

Children and adults working or living near e-waste recycling sites are susceptible to health problems related to e-waste. However, children are more affected due to high gastrointestinal uptake of heavy metals (Song and Li, 2015). Song and Li (2015) documented increases in spontaneous abortions, stillbirths, premature births, reduced birth weights and infant lengths in pregnant women exposed to heavy metals from a e-waste sites etc. Changes in thyroid function, changes in cellular expression and function, adverse neonatal outcomes, changes in temperament and behaviour, and decreased lung function have been linked with exposure to e-waste (Grant et al., 2013). Cancer incidence in the e-waste disassembly sites was related to higher burdens of PBBs, PBDEs, and PCBs in kidney,

Table 10 *Environmental impact of e-waste recycling*

Country	Environmental media	Contaminants and concentrations	References
China	Dumpsite soil, sediment	Soil PAHs (593), sediment PAHs (514) and PCBs (743) µg/kg	Leung et al., 2006
China	Dust	Workshop dust: Pb (110 000), Cu(8360), Zn (4420), Ni (1500) mg/kg; Adjacent road dust: Pb (22600), Cu (6170), Zn (2370), Ni (304) mg/kg	Leung et al., 2008
China	Soil and vegetables	Soils: PAHs (0.13–10.6); vegetable PAHs (0.20–2.42) µg/g	Wang et al., 2012
India	Soil	V (24–37), Cr (46–160), Mn (286-849), Co (5.2–42), Cu (61.7–4790), Zn (126–2530), Mo (0.84–11.0), Ag (2.2–320) µg/g	Ha et al., 2009
Hong Kong	Soil	Total 16 PAHs 107–2300 ng/g, total PCBs (6.7–143.7) ng/g, PBDEs (27.5–32340 ng/g), Cr(7.05–1717), Cu(13.8–756), Cd (0.28–11.0), Pb (132–3254), Zn (123–1717) mg/kg	Lopez et al., 2011
Nigeria	Soil and plants	Soil: PAHs (116 mg/kg), PBDEs (37.7), PCBs (4.06) mg/kg; Pb (1535), Cu(4308) Cr (13.9), Ni (32.0), Cd (7.69), Mn (270) mg/kg; Plants: PAHs (15.0), PBDEs (31.1), PCBs (0.21) mg/kg; Pb (34.34), Cu (69.55) Cr (2.0) Ni (1.24) Cd (1.29) Mn (24.65) – Plants	Alabi et al., 2012
China	Biota (snails, prawns, fish, water snakes)	PBDEs (52.7–1702), PCBs (20.2–25958) ng/g	Wu et al., 2008

Table 11 *Indicators of health impacts of e-waste in developing countries*

Country	Indicators	Contaminants and concentrations	References
China	Blood	Pb (4.40–32.7) µg/Dl	Huo et al., 2007
China	Placenta	Pb (0.007–3.47), Ni (0.001–1.11) µg/g	Wang et al., 2012
Vietnam	Breast milk	PBDEs (20–250) ng/g),	Tue et al., 2010
China	Hair	Cu (39.8), Pb (49.5) µg/g	Wang et al., 2009
China	Hair	PBBs (57.8), PBDEs (29.6), PCBs (180) ng/g	Zhao et al., 2008

liver and lung (Zhao et al., 2009). Elevated levels of heavy metals and persistent organic pollutants in blood, placenta of babies, breast milk and hair of people living close to e-waste treatment sites have been documented, as shown in Table 11. Most of the reports are from China.

3.7 Solutions for Present and Future Challenges

3.7.1 Optimizing and Promoting E-Waste as a Resource

Considering the environmental and health risks of adopting inappropriate management options for e-waste, as well as the loss of valuable resources, it is necessary to seek eco-friendly and sustainable sound options throughout the life cycle of electronics. An analysis of the electronics life cycle indicates that material extraction and manufacturing steps, energy requirements in production and use, and the negative environmental effects of EoL management are of most concern (Nnorom, 2012a,b). The ever-increasing technological complexity of EEE and the ever- shortening product life expectancy compounds this. However, the consumer electronic industry in general has accomplished a greater deal in reducing its impact on the environment by focusing on efficient use of its products, reducing products energy consumption and implementing environmental management systems to make the manufacturing processes increasingly resource efficient (Haugen, 2002). However, much still needs to be done in finding short- to long-term solutions to WEEE management, especially in the developing countries.

3.7.2 Role of Product Design in Defining Product EoL Scenario

End-of-life strategies are particularly important for EEE and innovative measures are needed to manage this, since EEE product life depends more on technological obsolescence than on wear-out life. However, the EoL strategy chosen depends on the characteristics of the product. A good EoL strategy for any product is to choose the alternative that causes minimal environmental damage while maximizing reusability of the products and components.

As the sustainability debate progresses, there is an urgent need to control consumer issues and increasing waste generation in the EEE sector by extending the lifetime of electronic products (Boks et al., 1998). Product design and development are essential in ensuring that products pose minimum challenges to health and the environment. Consequently, within the sustainability framework, it is important that manufacturers set the right design priorities, taking into consideration the entire life cycle of the products. For instance, the design should take into consideration possible reuse options as well as the appropriate EoL scenario of the product, such as:

a. will a product be reused?
b. will a product be disassembled for components reuse?
c. will a product be shredded for material recovery (recycling)?
d. will a product be incinerated (with energy recovery)?
e. will the product be dumped to landfill? (Nnorom, 2012a,b).

These issues should be considered at the design stage in order to have products that meet the tenets of sustainable development. In dealing with e-waste, it is essential that reuse options be integrated into the design to reduce the volume generated. To achieve this, it is essential that designers adhere to the tenets of design for environment (DfE) or design for recycling (DfR) to ensure that products are built for reuse, repair, and/or upgradeability. Emphasis should be placed on the use of less toxic, easily recoverable, and recyclable materials that could be taken back for refurbishment, remanufacturing, disassembly, and reuse.

3.7.3 Recovering EoL Products

Today, material disposition is driven primarily by design and economics, and products or components that lack effective reverse logistics networks or are designed so that they cannot be economically re-manufactured or recycled are disposed of into the solid waste stream. Efforts to develop products with improved environmental performance should not be seen as a threat by electronics manufacturers, but rather as an opportunity to increase business ventures and sales and to create awareness in consumers that the enterprise is 'environmentally conscious'. In fact, a 2009 University of Illinois study observed that the present global e-waste management system is generally not sustainable because mechanisms for collecting, sorting, reuse, refurbishing, repairing, and remanufacturing are not well developed and/or implemented. The adoption of sustainable management strategies for end-of-life electronics is critical in averting the loss of precious scarce resources and the environmental consequences of inappropriate management practices. Product recovery, the broad set of activities designed to reclaim value from a product at end-of-life, is used to describe activities designed to reuse, recover, refurbish, remanufacture, demanufacture, or recycle durable product assets at the end of a product life-cycle.

Product recovery plays three main roles:

- it lessens the environmental and economic costs of waste disposal
- it reduces the economic cost of purchasing and processing of new materials. This is because reusing components from used products ensures that their embodied value is retained
- it can be used as an environmental marketing tool by companies to differentiate their products and services

Several authors have reviewed the complexity of developing an integrated recovery process for WEEE (Ferrer, 1997; Ahluwalia and Nema, 2006). End-of-life costs are dependent on reverse logistics costs, product disassembly costs, the net value of materials to be recycled or processed, and the likelihood and revenue from component reuse or remanufacturing (Spicer and Johnson, 2004).

The five common options for material recovery from EoL products are repair, refurbish, remanufacturing, cannibalization and recycling (Nnorom et al., 2007). Reuse and recycling of EoL electronics are very demanding but advantageous alternatives to incineration or landfill of electronic scrap (Knoth et al., 2002). Factors such as cost, labour availability, return flow volume, and optimal disassembly level determine what recovery processes are feasible (Ritchey et al, 2001). Recovery of EoL products is constrained by the large variety of product models available in the market, size changes, and compatibility issues (Kumar et al., 2005). Meanwhile, the decision to remanufacture, disassemble and then recycle, recycle without prior disassembly, or simply dispose of an EoL product is based on product durability, rate of technological obsolescence, product complexity, duration of a design cycle, and reason for redesign, among other factors.

A recent study (Sindiku et al., 2014) has underscored the importance of screening plastics from e-waste for hazardous substances such as brominated flame retardants prior to recycling; otherwise products from such recycled plastics may become future sources of contamination and human exposure to these chemicals with health risks. The screening study suggests that average PBDE levels (of c-OctaBDE + DecaBDE) in Nigerian-stockpiled CRT casings were

1.1% for TV and 0.13% for PC CRTs. These are above the Restriction of Hazardous Substances (RoHS) limit and should therefore be separated for RoHS-compliant recycling. The Nigerian e-waste inventory of 237,000 t of CRT plastic (Ogungbuyi et al., 2011) would therefore contain approximately 594 t of c-OctaBDE and 1,880 t of DecaBDE. In Nigeria, as in most developing countries, there is currently no adequate e-waste management, plastics separation or destruction capacity. The data highlighted the urgent need to develop environmentally sound management strategy for this large plastic material flow. It further raises the question: What can developing countries and CEIT do with WEEE plastics/polymer-containing BFRs that the original equipment manufacturers (OEMs) and electronics recycling industry cannot take back? What support can the global OEMs give that Africa can address and solve the WEEE polymer recycling and end-of-life management challenge?

Product recovery will be required to control the various inappropriate management practices of EoL electronics in the developing countries (such as disposal with solid waste, into surface water bodies and crude backyard recycling practices), save resources and ensure environmental protection. Remanufacturing is important in achieving a green economy and saving scarce resources (Nnorom, 2012a, b; 2013). Designing products for remanufacture is required to assure their adaptability to remanufacturing operations. For example, designing products with high levels of modularity will be required if the products are to be remanufactured at their EoL. Xerox has been cited frequently in literature as a leader in the remanufacturing of their copiers. Xerox concurrently designs manufacturing and remanufacturing facilities for new models of their copiers and, in steady state, most of their products are actually "newly remanufactured" copiers (Ishii, 1998). Xerox has saved hundreds of millions of dollars through asset recovery and remanufacturing programs, while having a significant positive effect on the environmental bottom line (Kerr and Ryan, 2001).

Similarly, manufacturers of EEE have advanced research into design for environment (DfE), and significant progress had been made in the past two decades. For instance, IBM has established a research arm called Design for Environment and has established a worldwide asset-recovery organization that has been providing global remanufacturing and refurbishment focus for corporate and institutional accounts. Remanufacturing of EEE is becoming increasingly necessary and important in ensuring that future economic and manufacturing growth is sustainable.

To avoid negative environmental impacts by today's practice in demand markets with slack environmental regulations, clean remanufacturing activities must be initiated at the returned product's origin (Kernbaum et al., 2006). The reuse of EoL EEE conserves resources and feedstock that supply steel, glass, plastics and precious metals. Such reuse activities also avoid air and water pollution as well as greenhouse gas emissions associated with material production and manufacturing. The reused resources in a remanufacturing operation are the material in the product, energy, machine time, labour and other costs that have accumulated in the new production process (Östlin et al., 2009).

3.7.4 E-Waste as a Resource for Socioeconomic Development

The semi-formal and informal take-back system for e-waste management and the recovery of valuable materials from these in developing countries are contributing to the socioeconomic development of these countries. Typical examples are Ghana and Nigeria in

Africa and China and India in Asia (Grant and Oteng-Ababio, 2012; Manhart et al., 2011; Ogungbuyi et al., 2012). Manhart et al., (2011) assessed the socioeconomic impacts of the second-hand EEE and e-waste recycling formal and informal sector in Nigeria as part of the Secretariat of Basel Convention (SBC) E-waste Africa Project (SBC, 2011). This study observed that both formal and informal operators and individuals in the (second-hand) EEE sector are partly organized in associations to protect their business interests. The E-waste Africa Project observed that no formal education is required for collecting and sorting of e-waste, or in recovering of valuables from the wastes. Despite the limited formal education, all the waste collectors and recyclers interviewed in the study had very good knowledge of the kind of wastes they were interested in collecting and recycling. A sizeable number of graduates are also in the business of repairing and refurbishing EoL EEE in Nigeria. The sector is male dominated (>70 %).

Ogungbuyi et al. (2012) observed that wages in the e-waste sector are structured according to the waste volumes collected or treated, and hence the motivation for most individuals is the economic returns/benefits rather than concern for the environment. Between 144 and 1985 kg/week of e-waste mixed with other metal scrap are collected by a waste picker. The collected e-waste is co-mingled with other metal scrap. Up to 80000 persons in Nigeria are involved in this sector. The main sources of collected materials are homes/dump sites, refurbishers, streets, and importers. The waste picker sells to scrap dealers or vendors.

A typical vendor gets N3000–N5000/week (approximately US$20–30) when he sells his scrap. Mobile phone repairers often require the customers to register by paying a certain fee before the phones are investigated for faults, a charge that is usually not part of the repair charge. Revenue per refurbished EEE is between N1000–N3000 depending on the nature of the fault; when faulty components or modules are to be replaced the charge may be higher. An estimated 52000 persons are engaged in the refurbishing business in Nigeria (Ogungbuyi et al., 2012).

Approximately 66–68% of EEE brought to repairers and refurbishers shops are effectively repaired. Un-repairable EEE abandoned in the repairers' shops are disposed of or sold between 6 months to 3 years (mean: 1.5 years) of storage in the repairer's shop. 12–25% of the refurbishers dispose of all e-waste generated in their operations with general waste. Others (estimated at 66%) store and sell the waste to collectors and dispose of the useless wastes with general waste. The metal/steel and the plastic sectors of the country have been the main beneficiary of the informal collection of scraps and recyclable items. The e-waste aspect is also becoming a profitable venture for those who export printed circuit boards through various informal channels of downstream vendors across political borders.

3.7.5 Urban Mining

The life cycle of EEE begins with development and production, followed by use and maintenance, and leads right up to the reuse and recycling of the product in whole or in part. If reuse is not possible, recycling should be given preference; only as a last resort should a product be incinerated or dumped in a landfill. Urban mining is increasingly being recognised as an important component of resource strategies of public authorities, not only because it contributes to environmental protection but also because it is a source of valuable recyclable materials.

Simoni et al. (2015) used the rare earth element (REE) group to illustrate an overview of information and knowledge gaps concerning urban mining. The analysis shows that rare earth element recycling can be more environmentally friendly than primary production, particularly if the latter comes from countries with weak enforcement of environmental legislation. On the other hand, REE recycling often cannot compete with large-scale primary production because market prices do not reflect the social and environmental impacts of production, and because the avoided impacts of waste decontamination and waste production are not considered. The analysis of urban mining potential can be used to support decision making and the setting of priorities for future research and public action. The findings of the study and expert opinions based thereon contribute to the selection of measures and the formulation of public waste management and resource strategies in general. Urban mining especially using crude technologies is presently ongoing in some cities in developing countries, in particular Chennai in India and Guiyu in China. In these cities, large quantities of discarded internally generated computers, phones and television sets as well as imported e-wastes are sorted, disassembled, crushed and eventually chemically treated to recover the precious metals and traces of rare earth elements.

Estimates show that metal deposits in e-waste are up to 40–50 times richer than ore extracted from mines. For example, one ton of gold ore yields about 5 grams of gold, but one ton of phone circuitry yields about 150 grams, 30 times as much (Harvey, 2013). Unfortunately, only about 15–20% of the world's e-waste (estimated at about 50 million tons/year globally by the United Nations Environment Programme) is recycled annually. It is unfortunate and ironic too that, even with all efforts at achieving resource conservation and sustainability globally, only about 15% of the estimated $21 billion worth of gold and silver used in electronics is recovered from e-waste worldwide (Harvey, 2013). Consequently, e-waste is a promising reserve of valuable resources for any urban miner. Urban mining presents an opportunity to reclaim and recycle precious metals and REEs from e-waste and this requires the use of state-of-the-art facilities to ensure high recovery rates and high purity of recovered material while ensuring that environmental standards are maintained.

3.8 Conclusions

Information and communication technology (ICT), driven by electrical and electronic equipment, especially computers and mobile phones, has in the last two to three decades transformed the world beyond imagination. It has become a critical factor in achieving sustainable development for developing countries and fostering productivity and innovation, as well as helping to achieve the Millennium Development Goals (MDGs). These countries have achieved rapid advances in ICT in recent years to bridge the digital divide with developed countries. The ICT explosion is facilitated by the import of second-hand or used computers and mobile phones from developed countries, especially Europe and North America, as most of the population in developing countries can not afford the price of new electronic gadgets.

However, the near-tsunami generation of e-waste, classified as hazardous waste under the Basel Convention, from unsustainable production and consumption of electronic products; and the export of e-waste from developed to developing countries that lack the infrastructure and resources for their environmentally sound management, with the externalization of the adverse effects, are the dark sides of the ICT revolution and the resultant globalisation of the e-waste challenge. E-waste contains hazardous substances such as heavy metals, cadmium, lead, and mercury, as well as persistent organic pollutants (POPs) such as polybrominated biphenyl ethers (PBDEs). The crude e-waste management methods prevalent in developing countries are environmentally unsound and have potential risks to human health and the environment. It has been predicted that by 2020 developing and CEIT countries will generate more e-waste than developed countries. E-waste has therefore become a global crisis, not only from its quantity, as the fastest growing waste stream in the world, but also from various hazardous contents such as heavy metals and endocrine-disrupting substances, e.g. brominated flame retardants. E-waste has thus become an important risk to health and the environment, especially in developing countries and CEITs.

E-waste is somehow a paradox as it is both a problem and an opportunity, since it also contains valuable ferrous (e.g. iron), non-ferrous (e.g. copper), precious (e.g. gold and silver) and strategic metals (e.g. indium, gallium) that are scarce and may be lost if e-waste is landfilled or improperly processed; including the uncontrolled open burning currently practised in developing countries and CEITs. It is noteworthy that approximately 40% of the heavy metals found in landfills come from electronic waste (Montrose, 2011).

The simultaneous depletion of key metals and minerals, and the continuous production of e-waste streams, are certainly risky situations. Hence, there is a need for a paradigm shift from a perception of e-waste as a waste-disposal problem to a resource-management challenge, in line with the Rio+20 outcome document, "The Future We Want", which also promotes a transition to a green economy. This would mean "mining" the e-waste streams for raw materials such as precious metals (e.g. gold, silver, copper,) and strategic minerals such as rare earth metals. This will slow down the extraction and depletion of minerals from the earth, reduce their waste, and lessen the environmental, human health, and other impacts associated with electronic gadgets production cycle, including the reduction of greenhouse gases emission. Thus, e-waste is of special interest because most of it contains strategic minerals whose recovery and recycling could be cost-effective, create employment, and help alleviate poverty. However, recycling of WEEE plastic containing brominated flame retardants poses a special challenge for developing countries, as the BFRs must be removed from plastic before recycling and reuse. Thus, e-waste is one of the environmental challenges of the 21st century. Developing countries require international support from the United Nations agencies and donors to solve the monumental challenges in acquiring the infrastructure, resources, and capacity necessary for environmentally sound management of e-waste for sustainable development.

References

Advanced Tropical Environment (ATE). (2012) Identification of the Magnitude of the Electrical and Electronic (E-Waste) Situation in South Africa: A Strategic Approach to International Chemicals Management (SAICM) E-Waste as an Emerging Policy Issue, Department of Environmental Affairs, People's Republic of South Africa.

Agamuthu, P., Herat, S. (2012) E-waste: A Problem or an Opportunity? Review of Issues, Challenges and Solutions in Asian Countries. *Waste Management and Research* 30(11): 1113–1129.

Ahluwalia, P.K., Nema, A.K. (2006) Multi-objective Reverse Logistics Model for Integrated Computer Waste Management, *Waste Management and Research*, 24: 514–27.

Alabi, O.A., Bakare, A.A., Xu, X., Li, B., Zhang, X. Huo, Y. (2012) Comparative Evaluation of Environmental Contamination and DNA Damage Induced by Electronic-Waste in Nigeria and China, *Science of the Total Environment*, 423: 62–72.

Araujo, M.G., Magrini, A., Mahler, C.F., Bilitewski, B. (2012) A Model for Estimation of Potential Generation of Waste Electrical and Electronic Equipment in Brazil, *Waste Management*, 32: 335–342.

Babayemi, J.O., Osibanjo, O., Weber, R. (2014) Assessment of Use, Reuse and End-of- Life Disposal and X-Ray Fluorescence Analysis Screening of Waste Mobile Phones in Nigeria, *Environmental Quality Management*, 23(4): 1–12.

Baldé, C. P., J. Huisman, F. Wang and L. Herreras (2014) WEEE Market Assessment, Deliverable 4.2 of Countering WEEE Illegal Trade Project (Internal document), United Nations University.

BAN/SVTC (Basel Action Network and Silicon Valley Toxics Coalition). (2002) Exporting Harm: The High-Tech Trashing of Asia, www.ban.org, www.svtc.org

Basel Action Network (BAN). (2011) Toxic Trade News: Cochin Port a Safe Conduit for Imported E-waste. Available at http://www.ban.org/January. 2012.

Betts K. (2008) Producing Usable Materials from E-waste, *Environmental Science and Technology*, 42: 6782–3.

Boks, C., Nilsson, J., Masui, K., Suzuki, K., Rose, C., Lee, B.H. (1998) An International Comparison of Product End-of-Life Scenarios and Legislation for Consumer Electronics, in *Proceedings of the International Symposium on Electronics and the Environment*, 1998.

Chan, J.K.Y., Xing, G.H., Xu, Y., Liang, Y., Chen, L.X., Wu, S.C., et al. (2007) Body Loadings and Health Risk Assessment of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans at an Intensive Electronic Waste Recycling Site in China, *Environmental Science and Technology*, 41: 7668–74.

CHEARI. (2013) *White Paper on WEEE Recycling Industry in China 2012*, 2013, China Household Electric Appliance Research Institute.

Chi, X. (2011) Informal Electronic Waste Recycling: A Sector Review with Special Focus on China, *Waste Management*, 31(4): 731–742.

Cobbing, M. (2008) Toxic Tech: Not in Our Backyard. Uncovering The Hidden Flows of E-Waste. Report from Greenpeace International. www.greenpeace.org/seasia/th/Global/seasia/…/2/e waste-report-full.pdf. *Accessed September 1, 2013.*

Davis, G., Herat, S. (2010) Opportunities and Constraints for Developing a Sustainable E-Waste Management System at Local Government Level in Australia, *Waste Management and Research*, 28, 705–713.

EU (2003) European Union WEEE Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE); European Commission. *Official Journal of the European Union: Luxembourg*, 2003; pp 24–38.

Ferrer, G. (1997) The Economics of Personal Computer Remanufacturing, *Resources Conservation and Recycling*, 21, 79–108.

Finlay, A., 2005, *E-Waste Challenges in Developing Countries: South Africa Case Study*. APC Issue Papers. Association for Progressive Communications. www.apc.org.

Grant, K., Goldizen, F.C., Sly, P.D., Brune, M., Neira, M., Berg, M. and Norman, R.E. (2013) Health Consequences of Exposure to E-Waste: A Systematic Review, *Lancet Global Health*, 1: 350–61.

Grant, R., Oteng-Ababio, M. (2012) Mapping the Invisible and Real "African" Economy: Urban E-Waste Circuitry, *Urban Geography*, 33: 1–21.

Ha, N.N., Agusa, T., Ramu, K., Phu, N., Tu, C., Murata, S., Bulbule, K.A., Parthasaraty, P., Takahashi, S., Subramanian, A., Tanabe S. (2009) Contamination by Trace Elements at E-Waste Recycling Sites in Bangalore, India, *Chemosphere*, 76: 9–15.

Harvey, G. (2013) The Potential of Urban Mining, *The Diplomat*, November 19, 2013, Accessed July 27, 2015 http://thediplomat.com/2013/11/the-potential-of-urban-mining/.
Haugen, H.M. (2002) Economic Forces Driving the Electr(On)Ic Industry Towards Sustainability. In *Proceedings of CARE INNOVATION*, Vienna. http://aix.meng.auth.gr/helcare/CARE02/Ordnerstruktur/Paper%20Presentation/0.10.pdf.
Hoang, A., Tseng, W., Viswanathan, S. and Evans, H. 2009. Life cycle assessment of a laptop computer and its contribution to greenhouse gas emission. Paper presented at the 8th World Congress of Chemical Engineering, Quebec, Canada, 23–7 Aug. 2009.Retrieved July 7, 2014 from www.docstoc.com/docs/75386698/Life-Cycle-Assessment-of-a-Laptop-Computer-and-its-Contribution-to greenhouse gas emission.
Huo, X., Peng, L., Xu, X., Zheng, L., Qiu, B., Qi, Z., Zhang, B., Han, D. and Piao, Z. (2007) Elevated Blood Lead Levels of Children in Guiyu, an Electronic Waste Recycling Town in China, *Environmental Health Perspectives*, 115: 1113–1117.
Ishii, K. (1998) Design for Environment and Recycling: Overview of Research in the United States. *CIRP 5th International Seminar on Lifecycle Engineering*, September 16–18, 1998, 1–10.
ITU (International Telecommunication Union). (2012) Measuring the Information Society. http://www.itu.int/en/ITU-D/Statistics/Documents/publications/mis2012/MIS2012_without_Annex_4.pdf. Accessed April 14, 2016.
Jhin, P. (2007) Collaboration Towards Information and Communications Technology for Development (ICT4D). Accessed on December 12, 2007 www.gkpcms.com/GK3/documents/07.12.12-GK3-SS4-Paul%20Jhin.pdf
Kang, H.-Y., Schoenung, J.M. (2005) Electronic Waste Recycling: a Review of U.S. Infrastructure and Technology Options, *Resources, Conservation and Recycling*, 45: 368–400.
Kernbaum, S., Franke, C., Seligar, G. (2006) Flat Screen Monitor Disassembly and Testing for Remanufacturing. In *Proceedings of LCE 2006, 13th CIRP International Conference in Life Cycle Engineering*, 435–440.
Kerr, W., Ryan, C. (2001) Eco-efficiency Gains from Remanufacturing: a Case Study of Photocopier Remanufacturing at Fuji Xerox Australia, *Journal of Cleaner Production*, 9: 75–81.
Knoth, R., Brandstotter, M., Kopacek, B., Kopacek, P. (2002) Case Study: Getting Most Value Out Of Used IT Equipment. In *Proceeding of the International Symposium on Electronics and the Environment* 2002 IEEE, May 6–9 2002. San Francisco, 280–283.
Kumar, V., Bee, D.J., Shirodkar, P.S., Tumkor, S., Bettig, B.P., Sutherland, J.W. (2005) Towards Sustainable Product and Material Flow Cycles: Identifying Barriers to Achieving Product Multi-Use and Zero Waste. In *Proceedings of IMECE 2005. 2005 ASME International Mechanical Engineering Congress and Exposition*, November 5–11, 2005 Orlando, Florida.
Leung, A., Cai, Z.W. and Wong, M.H. (2006) Environmental Contamination from Electronic Waste Recycling at Guiyu, Southeast China, *Journal of Material Cycles and Waste Management*, 8: 21–33.
Leung, A.O.W., Duzgoren-Aydin, N.S., Cheung, K.C.,Wong, M.H. (2008) Heavy Metals Concentrations of Surface Dust from e-Waste Recycling and Its Human Health Implications in Southeast China, *Environmental Science and Technology*, 42: 2674–2680.
Li, J.H., Gao, S., Duan, H.B., Liu, L.L. (2009) Recovery of Valuable Materials from Waste Liquid Crystal Display Panel, *Waste Management* 29:2033–2039.
Lopez, B.N., Man, Y.B., Zhao, Y.G., Zheng, J.S., Leung, A.O.W., Yao, J., Wong, M.H. (2011) Major Pollutants in Soils of Abandoned Agricultural Land Contaminated by e-Waste Activities in Hong Kong, *Archives of Environmental Contamination and Toxicology*, 61: 101–114.
Manhart, A., Amera, T., Belay, M. (2013) E-waste Country Study Ethiopia, StEP Green Paper, United Nations University/StEP Initiatives.
Manhart, A., Osibanjo, O., Aderinto, A., Prakash, S. (2011) Informal E-waste Management in Lagos, Nigeria - Socio-Economic Impacts and Feasibility of International Recycling Co-operations. Report

of Component 3 of the UNEP SBC E-waste Africa Project for Nigeria. Institute for Applied Ecology and Basel Convention Coordinating Centre for Africa (BCCC-Nigeria), Freiburg/Germany & Ibadan/ Nigeria.

MoEF. (2008) Guidelines for Environmentally Sound Management of E-waste. (As approved by Ministry of Environment and Forestry (MoEF), Letter No. 23–23/2007-HSMD, Delhi, India. March 12, 2008.

Montrose, P. (2011) Think before you Shuffle, News to Use (Wellcorps International). Available: http://www.wellcorps.com/Think-Before-You-Shuffle.html [5 January. 2012].

Ni, H.-G., Zeng, E.Y. (2009) Law Enforcement and Global Collaboration are the Keys to Containing E-Waste Tsunami in China, *Environmental Science and Technology*, 43: 3991–3994.

Nnorom, I.C, Ohakwe, J., Osibanjo, O. (2009) Survey of Willingness of Residents to Participate in Electronic Waste Recycling in Nigeria — A Case Study of Mobile Phone Recycling, *Journal of Cleaner Production*, 17(8): 1629–1637.

Nnorom, I.C. (2012a) Bridging the Digital Divide and Creating an ICT Dump: An Overview of the Unsustainability if Exporting Used and End-if-Life ICT-Wares to Developing Countries. In *E-Waste: Management, Types and Challenges*, ed. Y.C. Li and B.L. Wang. Nova Science Publishers, New York, 67–88.

Nnorom, I.C. (2012b) Nigeria: Remanufacturing in the Information and Communication Technologies (ICT) Sector, for Green Economy and Trade Opportunities. United Nations Environment Program, International Trade Centre. International Centre for Trade and Sustainable Development. http://www.unep.org/greeneconomy/Portals/88/documents/research_products/Tradeopportunities/Nigeria%20case%20study.pdf

Nnorom, I.C. (2013) Manufacturing: Case Study: Nigeria. Contribution to United Nations Environment Programme Report on: Green Economy and Trade Opportunities. UNEP; International Trade Centre, International Centre for Trade and Sustainable Development (ICTSD), October 9, 2012. http://www.unep.org/greeneconomy/ResearchProducts/GreenEconomyandTradeOpportunities/tabid/104305/language/en-US/Default.aspx Published in: UNEP (2013) Green Economy and Trade: Trends, Challenges and Opportunities, http://www.unep.org/greeneconomy/GreenEconomyandTrade. http://www.unep.org/greeneconomy/portals/88/getreport/pdf/fullreport.pdf

Nnorom, I.C., Osibanjo, O. (2008) Overview of Electronic Waste (E-Waste) Management Practices and Legislations, and Their Poor Applications in the Developing Countries, *Resources Conservation Recycling*, 52: 843–858.

Nnorom, I.C., Osibanjo, O. (2009a) Toxicity Characterization of Waste Mobile Phone Plastic, *Journal of Hazardous Materials*, 161: 183–188.

Nnorom, I.C., Osibanjo, O. (2009b) Heavy Metal Characterization of Waste Portable Rechargeable Batteries Used in Mobile Phones, *International Journal of Environmental Science and Technology*, 6(4): 641–650.

Nnorom, I.C., Osibanjo, O., Kanno, O., Onwughara, N, Chukwuma, R.C. (2010) Evaluation of Heavy Metal Release from the Disposal of Waste Computer Monitors at an Open Dump, *International Journal of Environmental Science and Development*, 1(3): 227–233.

Nnorom, I.C., Osibanjo, O., Nnorom, S. (2007) Achieving Resource Conservation in Electronic Waste Management: a Review of Options Available to Developing Countries, *Journal of Applied Science*, 7(20): 2918–33.

Nnorom, I.C., Osibanjo, O., Ogwuegbu, M.O.C. (2011) Global Disposal Strategies for Waste Cathode Ray Tubes, *Resources Conservation Recycling*, 55(3): 275–290.

Ogundiran M.B., Olujobi, T., Osibanjo O. (2014a) Composition and Management of Rechargable Electric Torch Wastes in Ibadan, Nigeria, *Journal of Material Cycles and Waste Management*, 16(1): 115–123.

Ogundiran, M.B., Oyetade, A., Babayemi, J.O., Osibanjo, O. (2014b) Potential Environmental Hazards of Non-rechargable Electric Torch Wastes in Nigeria, *International Journal of Environment and Waste Management*, 13(2): 115–130.

Ogundiran, M.B., Tordue, G.B., Babayemi, J.O., Osibanjo, O. (2015) Waste Rechargeable Electric Lamps: Characterisation and Recovery of Lead from their Lead-acid Batteries, *Journal of Material Cycles and Waste Management,* May 2015. DOI: 10.1007/s10163-015-0394-7.

Ogungbuyi, O., Nnorom, I.C., Osibanjo, O., Schluep, M. (2012) E-waste Country Assessment Nigeria. Report of Components 1 & 2 of the UNEP SBC E-waste Africa Project for Nigeria. Basel Convention Coordinating Centre for Africa (BCCC), EMPA. Available at http://www.ewasteguide.info/Ogungbuyi_2012_BCCC-Empa.

Ogungbuyi, O., Nnorom, I.C., Osibanjo, O., Schluep, M. (2012) E-waste Country Assessment Nigeria, e-waste Africa Project of the Secretariat of the Basel Convention. http://www.basel.int/Implementation/TechnicalAssistance/EWaste/EwasteAfricaProject/tabi 2546/Default.aspx.

Ogushu, Y., Kandlikar, M. (2007) Assessing Extending Producer Responsibility Laws in Japan, *Environmental Science and Technology*, 41(13): 4502–4508.

Organisation for Economic Cooperation and Development (OECD). (2001) Extended Producer Responsibility: A Guidance Manual for Governments. Paris OECD; 2001. Avaialable at http://www.oecd-ilibrary.org/environment/extended-producer-responsibility_9789264189867-en

Osibanjo O. (2009b) Electronic Waste: a Major Challenge to Sustainable Development in Africa. Paper presented at *R'09 Twin World Congress and World Resources Forum*, Davos, Switzerland. September 14–16, 2009.

Osibanjo, O. (2009a) E-Waste Control Along the Supply Chain: Challenges and Prospects. Paper presented at *National Environmental Standard Regulation and Enforcement Agency (NESREA) International Conference on E-Waste Control,* Abuja-Nigeria, July 20–21, 2009.

Osibanjo, O. (2015) Gender and E-waste Management in Africa, in *Gender Heroes: From Grassroots to Global Action: a Collection of Stories Featuring Gender Perspectives on the Management of Hazardous Wastes.* Basel Rotterdam and Stockholm Conventions Secretariat (BRS), April 2015.

Osibanjo, O., Nnorom, I.C. (2007) The Challenge of Electronic Waste (E-waste) Management in Developing Countries, *Waste Management Research*, 25: 489–501.

Osibanjo, O., Nnorom, I.C. (2008) Material Flows of Mobile Phone and Accessories in Nigeria: Environmental Implications and Sound End-of-Life Management Options, *Environmental Impact Assessment Review*, 28: 198–213.

Östlin, J., Sundin, E., Björkman, M. (2009) Product Life-Cycle Implications for Remanufacturing Strategies, *Journal of Cleaner Production*, 17: 999–1009.

Osuagwu, O.E., Ikerionwu, C. (2010) E-cycling E-waste: The Way Forward for Nigeria IT and Electro-Mechanical Industry, *International Journal of Academic Research*, 2(1): 142–149.

Pinto, V.N., Patil, D.Y. (2008) E-waste Hazards: The Impending Challenge, *Indian Journal of Occupational and Environmental Medicine*, 12(2): 65–70.

Puckett, J. and T. Smith (eds), (2002) Exporting Harm: the High Tech Trashing of Asia. Basel Action Network and Silicon Valley Toxics Coalition (Online). Available at http://www.ban.org/E-waste/technotrashfinalcomp.pdf (accessed 25 April 2013).

Puckett, J., Westervelt, S., Gutierrez, R., Takamiya, Y. (2005) The Digital Dump: Exporting Reuse and Abuse to Africa. BAN media release version, Seattle.www.ban.org.

Raghupathy, L., Krüger, C., Chaturvedi, A., Arora, R., Henzler, M.P. (2010) E-waste Recycling in India: Bridging the Gap between the Informal and Formal Sector. Accessed January 5, 2012, http://www.iswa.org/fileadmin/galleries/General%20Assembly%20and%20WC%202010%2011%20Hamburg/Presentations/Krueger.pdf

Ritchey, J., Mahmoodi, F., Frascatore M, Zander A (2001). Assessing the Technical and Economic Feasibility of Remanufacturing: Environmental Issues, In *Proceedings of the Twelfth Annual Conference of the Production and Operations Management Society* POM-2001, March 30-April 2, 2001, Orlando, FL.

Robinson, B.H. (2009) E-waste: An Assessment of Global Production and Environmental Impacts, *Science of the Total Environment* 408: 183–191.

Rochat, D., Hagelüken, C., Keller, M., Widmer, R. (2007) Optimal Recycling for Printed Wiring Boards (PWBs) in India. In *R'07 Recovery of Materials and Energy for Resource Efficiency*, 12, Davos, Switzerland.

SBC (2011) *Where Are WEee in Africa? Findings from the Basel Convention e-Waste Africa Programme*. Geneva/Switzerland. Secretariat of the Basel Convention.

Schluep, M., Hagelueken, C., Kuehr, R., Magalini, F., Maurer, C., Meskers, C., Mueller, E., Wang, F. (2009) *Recycling — from E-waste to Resources, Sustainable Innovation and Technology Transfer Industrial Sector Studies*. Paris, France: United Nations Environment Programme (UNEP).

Schluep, M., Terekhova, T., Manhart, A., Muller, E., Rochat, D., Osibanjo, O. (2012). Where Are WEEE in Africa? 2012 Electronics Goes Green 2012+ (EGG).

Schmidt, C.W. (2006) Unfair Trade — E-waste in Africa, *Environmental Health Perspectives*, 114: 232–235.

Sepúlveda, A., Schluep, M., Renaud, F.G., Streicher, M., Kuehr, R., Hagelüken, C., Gerecke, A.C. (2010) A Review of the Environmental Fate and Effects of Hazardous Substances Released from Electrical and Electronic Equipments During Recycling: Examples from China and India, *Environmental Impact Assessment Review*, 30: 28–41.

Simoni, M., Kuhn, E.P., Morf, L.S., Kuendig, R., Adam, F. (2015) Urban Mining as a Contribution to the Resource Strategy of the Canton of Zurich., *Waste Management*, doi:10.1016/j.wasman.2015.06.045

Sindiku, O., Babayemi, J., Osibanjo, O., Schlummer, M., Schluep, M., Weber, R., (2014) Polybrominated Diphenyl Ethers Listed as Stockholm Convention Pops and Other Brominated Flame Retardants and Heavy Metals in E-Waste Polymers in Nigeria, *Environmental Science and Pollution Research*, 22(19): 14489–14501.

Sinha-Khetriwal, D., Kraeuchi, P., Schwaninger, M. (2005) A Comparison of Electronic Waste Recycling in Switzerland and in India, *Environmental Impact Assessment*, 25: 492– 504.

Smith, T., Sonnenfeld, D.A., Naguib-, Pellow, D. (2006) Challenging the Chip: Labour Rights and Environmental Justice in the Global Electronics Industry (Philadelphia, PA, Temple University Press).

Song, Q., Li, J. (2015) A Review on Human Health Consequences of Metals Exposure to E-Waste in China, *Environmental Pollution*, 196: 450–461.

Spicer, A.J., Johnson, M.R. (2004) Third-party Demanufacturing as a Solution for Extended Producer Responsibility, *Journal of Cleaner Production*, 12: 37–45.

StEP — Solving the E-Waste Problem. (2012). What is E-waste? Accessed July 7, 2013, http://www.step-initiative.org/index.php/Initiative_WhatIsEwaste.html.

Tsydenova, O., Bengtsson M. (2009) Environmental and Human Health Risks Associated with the End of-Life Treatment of Electrical and Electronic Equipment, *Institute for Global Environmental Strategies (IGES), Integrated Waste Management and Resource Efficiency Project*, Hayama, Kanagawa, Japan: 2009, pp. 1–49. (www.iges.or.jp)

Tue, N.M., Sudaryanto, A., Minh, T.B., Isobe, T., Takahashi, S., Viet, P.H., Tanabe, S. (2010) Accumulation of Polychlorinated Biphenyls and Brominated Flame Retardants in Breast Milk from Women Living in Vietnamese E-waste Recycling Sites, *Science of the Total Environment* 408, 2155–2162.

UNEP (2006) E-waste: The Hidden Side of IT Equipment's Manufacturing and Use". *Early Warnings on Emerging Environmental Threats No. 5*, United Nations Environment Programme (UNEP), Geneva.

UNEP (2011) Study on the Possible Effects on Human Health and the Environment in Asia and the Pacific of the Trade of Products Containing Lead, Cadmium and Mercury: Draft Final. Accessed August 5, 2013, http://www.unep.org/hazardoussubstances/Portals/9/Lead_Cadmium/docs/Trade_Reports/AP/Rev_Draft%20Asia%20and%20Pacific%20Pb%20Cd%20Hg.pdf.

UNEP (2007) E-waste Volume I: Inventory Assessment Manual. United Nations Environmental Programme Division of Technology, Industry and Economics, International Environmental Technology Centre Osaka/Shiga. http://www.unep.org/ietc/Portals/136/Publications/Waste%20Management/EWasteManual_Vol1.pdf.

Wang, F., Kuehr, R., Ahlquist, D., Li, J. (2013) E-waste in China: A Country Report. StEP Green Paper Series. Accessed October 30, 2013, http://www.ehs.unu.edu/file/get/11082.pdf.

Wang, T., Fu, J., Wang, Y., Liao, C., Tao, Y., Jiang, G. (2009) Use of Scalp Hair As Indicator of Human Exposure to Heavy Metals in an Electronic Waste Recycling Area, *Environmental Pollution*, 157: 2445–2451.

Wang, Y., Tian, Z., Zhu, H., Cheng, Z., Kang, M., Luo, C., Li, J., Zhang, G. (2012) Polycyclic Aromatic Hydrocarbons (PAHs) in Soils and Vegetation Near an E-waste Recycling Site in South China: Concentration, Distribution, Source, and Risk Assessment, *Science of the Total Environment*, 439: 187–193.

Wath, Sushant B., Dutt, P.S., Chakrabarti, T. (2011) E-waste Scenario in India, *Its Management and Implications, Environmental Monitoring and Assessment* 172: 249–262.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, A., Scnellmann, M. and Boni, H. (2005) Global Perspectives on the E-waste, *Environmental Impact Assessment Review*, 25: 436–458.

Wu J.-P., Luo, X.-J., Zhang, Y., Luo, Y., Chen, S.-J., Mai, B.-X., Yang, Z.-Y. (2008) Bioaccumulation of Polybrominated Diphenyl Ethers (PBDEs) and Polychlorinated Biphenyls (PCBs) in Wild Aquatic Species from an Electronic Waste (E-Waste) Recycling Site in South China, *Environment International*, 34: 1109–1113.

Zhao, G., Wang, Z., Dong, M.H., Rao, K., Luo, J., Wang, D., Zha, J., Huang, S., Xu, Y., Ma, M. (2008) PBBs, PBDEs, and PCBs levels in Hair of Residents Around E-Waste Disassembly Sites in Zhejiang Province, China, and Their Potential Sources, *Science of the Total Environment*, 397: 46–47.

Zhao, G., Wang, Z., Zhou, H., Zhao, Q. (2009) Burdens of PBBs, PBDEs, and PCBs in Tissues of the Cancer Patients in the E-Waste Disassembly Sites in Zhejiang, China, *Science of the Total Environment*, 407: 4831–4837.