Policy issues for efficient management of E-waste in developing countries

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Rajiv Ranjan Srivastava[1,2] and *Pankaj Pathak*[3]
[1]Center for Advanced Chemistry, Institute of Research and Development, Duy Tan University, Da Nang, Vietnam, [2]Research & Operation, Evergreen Recyclekaro India Pvt. Ltd. (Recyclekaro.com), Navi Mumbai, Maharastra, India, [3]Department of Environmental Science & Engineering, Marwadi Education Foundation, Rajkot, Gujarat, India

4.1 E-waste and its management

Electronic (e-) waste is globally regarded as a subset of waste electrical and electronic equipment (WEEE). The most prominent definition of E-waste/WEEE can be referred through the description given by the European Commission as "the end-of-life (EoL) commodity/gadgets that have been used for generating, measuring, and transferring the electrical or magnetic current, and/or functioned by supplying the current during their service life." In this ways, certainly not limited to, the discarded electronic goods (e.g., personal computers and hand/telephones), electrical appliances (e.g., air conditioners, refrigerators, and washing machines), and power storage batteries are belonging the E-waste. Another definition given by the Association of Plastics Manufacturers in Europe (APME) has stated E-waste as the multifarious combination of ferrous, nonferrous, ceramic, and plastic materials.

A rapidly changing technology and its unprecedented use in our daily life are generating a large volume of EoL materials those have been kept within the boundary of E-waste. With an annual growth rate of more than 4%, E-waste is the enormously growing waste volume around the globe. In 2014, approximately 41.8 Mt (million tons) of E-waste was generated worldwide, which reached 44.7 Mt in 2016 (equivalent to 6.1 kg/inhabitant), and estimated to touch 50 Mt by the end of year 2018 (https://tcocertified.com/news/global-e-waste-reaches-record-high-says-new-un-report/; https://www.forbes.com/sites/lamsharon/2017/11/23/global-e-waste-to-hit-49-8m-tons-by-2018-heres-what-japan-is-doing-to-combat-it/#6489acd335ca). At the regional level, Asia is the top generator of E-waste (~41%), followed by the United States (~29%), and Europe (~27%); however, Europe is top in the generation by per inhabitant. The gap in E-waste generation between the developed and developing countries is very wide. The richest country is generating 19.6 kg/inhabitant against the poorest country of only 0.6 kg/inhabitant. Although the developed countries have covered themselves from the adversaries of E-waste under the umbrella of advanced technology and management system, developing and

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underdeveloped countries are still struggling to get proper guidelines for effective management of E-waste. In those countries, specifically low and middle income-group countries, a large proportion of E-waste is either disposed in landfill sites or, fed to the informal recycling sector. The burning of end-of-life wires and printed circuit boards (PCBs) are a common practice to separate metal and polymer substance. Rudimentary methods, including the hand-picking and dismantling, nitrate/aqua-regia leaching, and throwing the residual and effluent streams in an open environment is also practiced to retrieve the precious metals from E-waste. Therefore lacking safeguard to the environment and public health with an inappropriate efficiency of resource recycling (Leung et al., 2006; SEPA, 2011).

4.2 Current practices of E-waste management

In the global framework for an effective E-waste management, the collection, handling, processing (recycling and recovery), and final disposal are accepted as the main factors (E-waste management rule, 2016). On the other side, threats from improper handling of greater volume by the informal recycling with weak/absent of E-waste legislation are the major issues identified for developing countries (Heeks et al., 2015). However, the role of informal sectors in low and middle income countries cannot be ignored (Pathak et al., 2017). Fig. 4.1 depicts the current practices of E-waste management system where it is collected from sales, households, business, and public sectors after attaining the EoL. Below the aggravated management of thus generated E-waste volume in developing countries of more relevance is discussed.

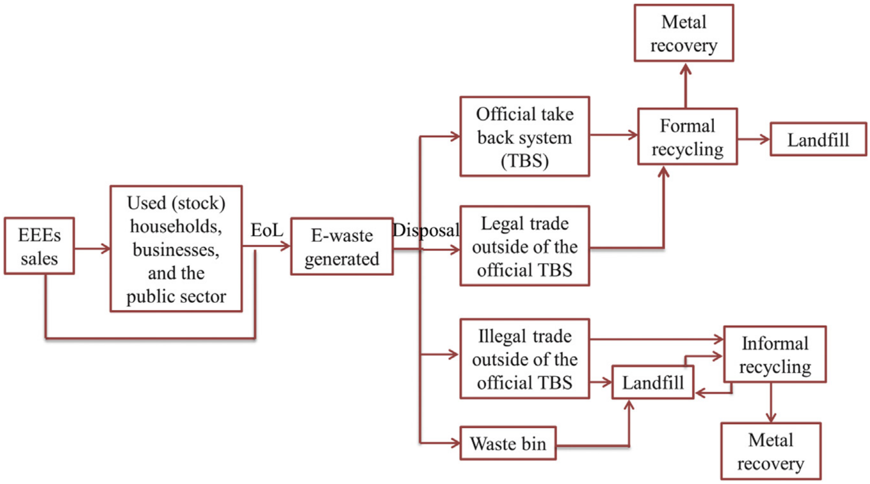

Figure 4.1 Pictorial representation of a typical E-waste management system (Balde et al., 2015; Pathak et al., 2017).

4.2.1 China

In the last 5 years, the Asia-Pacific region has 63% jumped in global E-waste generation that accounted for 16 Mt in weight (https://www.theguardian.com/environment/2017/jan/16/chinas-booming-middle-class-drives-asias-toxic-e-waste-mountains). Amongst all, the domestic E-waste production in China has been recorded more than doubled to 6.7 Mt during the same period (https://www.recycling-magazine.com/2017/10/19/electronics-recycling-china/). It makes China the largest producer of E-waste, alone contributing around 15% of the global volume (https://i.unu.edu/media/unu.edu/news/52624/UNU-1stGlobal-E-Waste-Monitor-2014-small.pdf; https://www.chinadialogue.net/article/show/single/en/9841-China-to-release-plan-for-tackling-e-waste-by-end-of-year-).

Nevertheless, the domestic generation of E-waste has remained smaller if compared to the amount of E-waste being imported from developed countries to China, which has accounted up to 35 Mt (Ongondo et al., 2011). Owing to the problems E-waste carry in terms of quantity and toxicity, China is the largest importer of these challenges. Mostly the imported E-waste ends through practicing the primitive process by the informal sector. The informal recycling sector practices the primitive processes without any proper scientific facilities and safeguards to the environment and human health (Green Peace-Basel Action Network, 2004). Usually, it is a kind of family-run workshop within their house or surroundings where disassembling of E-waste and metals stripping by open acid bath or burning of PCBs and wire/cables are practiced (Leung et al., 2006). Such activities caused severe problems in the form of environmental pollution nearby the informal recycling areas, like Guiyu where the accumulation of heavy metals and hazardous hydrocarbons have been measured in the soil, air, and water (Yu et al., 2010; Bridgen et al., 2005; Zhang and Min, 2009). Notably, Guiyu is an archetype of “backyard” E-waste processing by 1995, employing 150,000 peoples in approximately 5500 shops (Driscoll and Shiheng, 2010).

Time-to-time the environmentalists, researchers, and media has brought attention to its environmental impacts (Hicks et al., 2005; Basel Action Network, 2002). Therefore it is needed for China to develop the systems to handle domestically generated E-waste and its international trade as well. Henceforth, the Chinese government is continuously working to develop the policies, infrastructure facilities, and technologies for the effective management of E-waste. In this direction, the specific and pertinent efforts in the form of regulations and laws enacted by the Chinese government are summarized in Table 4.1.

The Management of Prevention and Control of Pollution from Electronic Information Products (EIPs) referred as China’s RoSH and the waste disposal law dealing for the administration of the recovery and disposal of E-waste are of vital importance. They basically target by funding safe E-waste recycling facilities, also the responsibility of E-waste collection is fixed on the manufacturers/retailers/recycling companies.

4.2.2 India

India stands fifth for generating the E-waste worldwide. A compound growth of 25% per annum, generating 1.85 Mt E-wastes has been estimated in 2016 (ASSOCHEM

Table 4.1 Laws and regulations related to E-waste management in China (MEP, 2003, 2007, 2009; MIIT, 2006; Yang et al., 2008; Streicher and Yang, 2007).

Regulations	Status/ date	Major contents
Notification on Importation of the Seventh Category Waste	February 1, 2000	Ban on the import of the seventh category of waste
The circular on strengthening environmental management of waste electrical and electronic equipments (WEEE)	August 26, 2003	Prohibit the environmentally harmful processing of WEEE; encourage electronic product manufacturers to promote cleaner production and eco-design
The Ordinance on Management of Prevention and Control of Pollution from Electronic Information Products [The Ministry of Industry and Information Technology (MIIT), 2006]	November 6, 2006	Aims to reduce the utilization of hazardous and toxic substances in electronic appliances as well as the pollution generated due to the manufacture, recycling and disposal of these products. It is the counterpart of the EU RoHS directive, including requirements for eco-design; restrictions on the use of six hazardous substances
The Technical Policy on Pollution Prevention and Control of WEEE (MEP)	April 27, 2006	Set forth the guiding principles of "3R" and "polluter pays principle"; stipulates the general provisions of eco-design, the information disclosure of products, and provisions environmentally sound collection, for the reuse, recycling and disposal of WEEE
The ordinance on management of prevention and control of pollution from electronic and information products (MIIT)	March 1, 2007	Requirements for eco-design; restrictions on the use of hazardous substances; requirements for producers to provide information about their products
Administrative measure on pollution prevention of waste electrical and electronic equipments (MEP)	February 1, 2008	Intend to prevent the pollution caused during the disassembly, recycling and disposal of E-waste; specifies responsibilities of relevant parties and the licensed scheme for E-waste recycling companies
Circular economy law	January 1, 2009	Specify provisions on reduce, reuse and recycle (3R) of electronic products during the production, consumption and other processes

(*Continued*)

Table 4.1 (Continued)

Regulations	**Status/ date**	**Major contents**
Regulation on management of the recycling and disposal of waste electrical and electronic equipments	January 1, 2011	Mandatory recycling of WEEE; implementation of extended producer responsibility; establish of a special fund to assist E-waste recycling; certification for second hand appliances, and recycling enterprises

India report 2016). However, the volume coming from OECD countries contributes 50%−60% of the total E-waste in India that makes its precise quantification a difficult task (Borthakur and Sinha, 2013; Pathak et al., 2017). Mumbai (1.2 Mt) tops in the list, while Delhi-NCR (98,000 t), Bangalore (92,000 t), Chennai (67,000 t), Kolkata (50,000 t), Ahmedabad (36,000 t), Hyderabad (32,000 t), and Pune (25,000 t) are the major metro city in the list (The digital dump, 2013). The main designated E-waste and their generation in India are given in Table 4.2. It has been understood that a rapid economic growth with enhanced purchasing capacity of the expanded middle-income urban society gives exponential rising to E-waste generation. Adopting a predictive mathematical modeling, Pathak et al. (2017) quantified the two most sellable electronic items of the Indian market, computers and mobile phones. It has been found that the E-waste volume of computers will continue to increase until 2022, thereafter, slowly reaching a saturation point by 2028. On the other side, no saturation point could be observed for the E-waste from mobile phones.

Looking at such scenario of E-waste generation and its reported adversity to the sustainability, India has drawn a legislative frame to overcome from this problem. The chronological developments in the legislative framework of E-waste management are summarized by Pathak et al. (2017), which clearly depicts that it took three decades to come with an E-waste specific legislation, E-waste Management Rule 2016. After introducing the extended producer responsibility (EPR) in 2010, the responsibilities of manufactures and refurbishers are incorporated in 2016 (Pathak et al., 2017, 2019).

The advent of E-waste legislation has increased the awareness for its management, and hence, some collection centers, organized recycling companies, and local body's society have started to emerge albeit yet contributing small. Reducing the E-waste volume and recovery of valuable and critical metals are the benefits of recycling are being practiced by several recyclers in organized and scientific manner like Recyclekaro.com, E-Parisaraa, E-waste Recycling India, and Green India E-waste & Recycling Opc Pvt. Ltd. It has been considered a positive but slow start due to still handling of 90% E-waste by the unorganized sector, employing 0.5 million child workers in India (http://assocham.org/newsdetail.php?id = 4633Assocham%20/).

Table 4.2 Types and generation of WEEE in India (Pathak et al., 2017).

E-waste type		**Households**	**IT and communication equipments**	**Consumer electronics**	**Total E-waste generation in India (Mt/year)**
Description of items included		LCD/plasma TVs, air conditioners, refrigerators, washing machine, microwave oven, and mixture grinder	Monitors, printers, keyboards, central processing units, typewriters, mobile phones, chargers, remotes, compact disks, headphones, batteries, and semiconductors	DVDs and players, video games, iPods, and remote control cars	
E-waste (Mt/year)	2012	0.07	0.35	0.02	0.44
	2014	0.20	1.04	0.07	1.30
	2016	0.28	1.48	0.09	1.85
	2018	0.39	2.09	0.13	2.61
	2020	0.50	2.65	0.17	3.31

Most of the unorganized recycling activities are going on either within the metro cities or, in the nearby smaller towns (Dwivedy and Mittal, 2012).

4.2.3 Brazil

Brazil is the second largest E-waste producer among the American countries. Currently, Brazil produces 1.5 Mt E-wastes, just behind the United States of 6.3 Mt. It was only 0.67 Mt in last decade, mostly in the form of televisions, mobile phones, radios, computers, refrigerators, and washing machines. As estimated, the average per capita E-waste generation in between the years 2001–30 is above 3.4 kg that may require the disposal of an accumulative volume of ~25 Mt of E-waste by 2030.

The increasing volume of E-waste has caused for the concern regarding its proper management, and a national law "Law of the Garbage" has been introduced by stating everyone's responsibility for concerning on E-waste generation. This applies to manufacturers, retails, government organizations and officials, and end-user as well. The Federal Law No. 12.305 approved on August 2010 by the National Solid Waste Policy, ensures a proper treatment of E-waste. The State law (No. 13.576) enacted in São Paulo in July 2010 ensures the procedures responsibility for the formal treatment of E-waste that includes recycling, management, and disposal. Including the principle of shared responsibility (PSR) on the life cycle of EEE, the regulatory framework has recognized the solid waste as the reusable and recyclable waste. However, in Sao Paolo and on the federal level strong opposition from producers was reported (Silva et al., 2008).

Moreover, E-waste has been taken as an economic asset with societal value due to the ability of job creation. Under the umbrellas of federal and state laws, Brazil has specialized E-waste management companies. Ecobraz (specialized in collection and recycling of obsolete electronics), Reciclagem Brasil (specialized in providing E-waste a proper destination for recycling), CEDIR (sends E-waste to recycling companies), Coopermiti (offers management, processing, and recycling of E-waste in cooperation with the Prefeitura Municipal de Sao Paulo), Descarte Certo (offers collection and recycling services at large scale), Estre (recycles all kind of E-waste), Lorene (operates in all part of E-waste treatment), RecicloMetais (provides E-waste treatment at all stages), and Recicladora Urbana (offers reverse logistics and waste management services) are the major players in this field (https://techin-brazil.com/e-waste-management-in-brazil). Once collected, the E-waste goes through a dismantling process for individual classification of each component. Thereafter, the recycling companies do processing for recovering the raw materials like plastics, metals, wires, and cables, while neutralizing the hazardous substances through specific chemical processing.

4.2.4 Argentina

E-waste is also an increasing concern in Argentina that is growing with the pace of technological advancements. A 2.5 kg E-waste per inhabitant is estimated to generate on yearly basis in Argentina, which reflects the generation of a total 0.1 Mt E-waste per year. Approximately 25% of which is belonging to obsolete and telecommunications and computers. Similar to others, the recycling rate of E-waste is also very poor in Argentina that is accounted only a 2% of the total amount of E-waste generated per year. The participation of governmental organization is also very limited to less than 5% of the total amount of E-waste processed. This situation becomes more alarming when the white goods and other consumer electronics are included, which gives the E-waste generation data 7.8 kg/inhabitant for the year 2018 (https://www.statista.com/statistics/727725/ewaste-generation-argentina/). In lacking a specific law on E-waste regulation, Argentina has a robust informal sector for the management E-waste, and recycling is majorly controlled by the social marginal and unemployed groups (https://www.giswatch.org/country-report/2010-icts-and-environmental-sustainability/argentina). E-scrap, EcoGestionar, Scrapy Rezagos, Silkers, and Ecotech are a few names involves in the formal recycling of E-waste in Argentina. Some NGOs works for the refurbishing of computers for charity purposes, while a few operates for the takeback program of obsolete or UEEE, hence, their significant volumes end-up in the municipal waste.

In accordance with the article 41 of the constitution that "all inhabitants have the right to a healthy, balanced environment, suitable for human development" and "the prohibition of entry of actual or potentially hazardous waste into the country" is promised. In absence of EPR-type legislation, Argentina looks E-waste problem in the frameworks of Basel Convention and Mercosur agreement on an environmental management policy for universally generated special wastes and postconsumption responsibility (First Extraordinary Meeting of Environmental Ministers, 29 March, Curitiba, Brazil). Presenting a paradox while keeping the country from becoming a dump-yard of E-waste, the possibility of local enterprises expansion and prevention of E-waste disposal are also hindered. Hence, a national plan on integrated E-waste management in 2005 by ratifying the Basal Convention, and guiding principles on E-waste management for the companies were initiated, but bills pending in the legislature lost parliamentary status (Silva et al., 2008; www.rezagos.com/descargas/Proyecto-Ley-RAEE.pdf; www.rezagos.com/descargas/ProyectoLeyRAEE-UTN.pdf).

4.2.5 Nigeria

Nigeria is also a favorite dumping yard of the E-waste generated by developed countries. The awareness and action in regulatory bodies among the major Asian destination countries China, India, and Pakistan has also caused an increased flow of E-waste to Nigeria. Again in the name of UEEE, Nigeria received 66,000 t of old computers, televisions, and monitors during the year 2015−16. Out of which, approximately 16,900 t of UEEE was already in not-working condition (https://www.ehn.org/how-much-e-waste-is-shipped-to-nigeria-2561214315.html). An interesting study has reported that despite the stringent laws in EU for E-waste trades, around 70% of the total E-waste in Nigeria is coming from Europe. In most of the cases, it is kept inside the old vehicles to trespass E-waste to Nigeria (http://collections.unu.edu/eserv/UNU:6349/PiP_Report.pdf; https://motherboard.vice.com/en_us/article/59jew8/e-waste-smuggling-nigeria).

In such way E-waste reached Nigeria (specifically at the Lagos seaport), the brokers/importers provide the passage for the illegal entry under the umbrella of Computer and Allied Product Dealer Association of Nigeria (CAPDAN, a regulatory body coordinating the affairs of IT industry) (https://ejatlas.org/conflict/e-waste). The importers purchasing containers by its weight, and after shorting the good working gadgets for repairing/refurbishing they are sold either in the Ikeja Computer village or, Alaba International market. The nonworking gadget are directly sent to land-fills spread around the city but officially goes to Lagos Olusosun, Igodun, and Ikorodu dumpsites (Babatunde, 2016; Ideho, 2012). There several thousand individual workers are living on or next to dumping yards, including minor children involved in the collection, sorting, dismantling, and metal stripping from the E-waste. They either directly deal with smelter/refineries or, sell to middle-man. Such informal practice causing the environmental and health loss and creates disputes between individual groups of scavengers. Besides this, the domestic E-waste generation rate of Nigeria is also high albeit that is also largely contributed by the EoL-UEEE. The life of repaired/refurbished mobile phones in Nigeria extends up to 7 years. But at the cost of twice a year replacement of batteries and chargers that generates an additional amount of E-waste, estimated to be more than 1 Mt (Nnorom and Osibanjo, 2008).

Looking at the vulnerable situation, Nigeria has approved the opening of its first formal E-waste recycling plant operated by Hinckley Recycling at Ojota in Lagos state (https://www.dailytrust.com.ng/nigeria-gets-first-e-waste-recycling-facility.html). Although Nigeria does not have potent enforcement of specific regulations on E-waste management (Nnorom and Osibanjo, 2008), the move is an appreciative one. Recently, it has implemented the National Environmental Regulations (Electronics Sector) that explicitly prohibits only the trade of unusable electronic goods.

4.3 Policy comparison between developed and developing countries

Although a slow rate of technological advancement in the developing countries, they are currently consuming the EEE at a faster rate than the developed countries. Therefore they also produce more E-waste, might be in doubled amount than the developed countries (Garlapati, 2016). For example, the discarded units of obsolete computers by developing and developed countries is estimated to be 400−700 million and 200−300 million, respectively, by 2030 (Sthiannopkao and Wong, 2013). But in lack of the proper rules and regulations, the developing countries are facing several-folds higher challenges than the developed countries. Therefore their comparison is worthy to discuss.

4.3.1 Comparison of rules and policies

A comparison of legislative policies between the developed and developing countries is summarized in Table 4.3. Nevertheless, many of the developing countries have started to prepare and enacted their specific policy on E-waste management, the developed countries are one step ahead due to the strict implementation of legislations.

In developed countries, the national registry system, along with the proper collection and logistics system is very strong (Sthiannopkao and Wong, 2013). The Avoidance of Packaging Waste of Germany is the first mandated EPR program that put financial obligations on manufacturers for collection and reduction of packaging waste (Ongondo et al., 2011; Van Rossem et al., 2006). Later, it is adopted and extended to EEE manufacturer by Sweden, Norway, Taiwan, and Switzerland. The EU legislation restricting the use of hazardous substances in EEE and WEEE/E-waste (Directive 2002/95/EC, the RoHS Directive), and promoting their collection and recycling (Directive 2002/96/EC), has been enacted in 2003 (EU RoHS Directive 2002/95/EC). Currently, the legislations in China and India have clearly implemented the EPR system in lacking of a national registry that keeps track of the produced EEE for the purpose of eventual manufacturer take-back, the generation of E-waste is difficult to trace. The big gray markets available for the second-hand UEEE in these countries is also making situation vulnerable, while comparing

Table 4.3 A comparative legislation/regulations in the developed and developing countries for dealing with E-waste (Pathak et al., 2017).

Developed countries	Developing countries
The United States: Responsible electronics recycling act came in 2011. Banned the export of WEEE item: PCs, TVs, printers, xerox, phones, CRTs, batteries, containing Pb, Cd, Hg, Cr, Be, and organic solvents	*China*: Restriction on junk electrochemical products and electrical items mainly for copper recycling. Catalog of restricted imports of solid wastes, 2008
The United Kingdom: Under EU directives in 2007. Adopted the EU directives	*India*: Import policy under 2005. Further, transboundary moment and EPR were introduced in E-waste rule 2011. Provided a strategy and method for treatment of E-waste
Belgium: Directive 2002/96/EC on WEEE, 2002. The Public Waste Agency of Flanders controls the waste management and responsibility of producer	*Pakistan*: Import policy order, 2009. Banned the import of refrigerator and air conditioners, and CRT can be imported only with used computers
France, Germany and the Netherland: Under EU directives in 2005. Limited use of toxic materials by the producers; collection and processing of used electronics by distributors and municipalities; France introduced an "eco-cost" for treating WEEE	*Thailand*: Criterion for import of used EEE (UEEE), 2007. Control on the classified UEEE
Japan: Law for the Control of export, import, and others of specified hazardous and other wastes. Export prohibited without consent from the import country	*Vietnam*: Law on environmental protection, 2005. Prohibits the movement of hazardous waste from abroad stipulates responsibilities for waste generator
Norway: The revised EU directives, 2006. A WEEE register established with mandatory membership for every producer and importer of an approved take-back company	*Nigeria*: Guide for importers of UEEE into Nigeria, 2011. Import of WEEE banned with a compulsory registration of importers
South Korea: Showed restriction on export, without consent from the importing country. They have transboundary movement act on hazardous wastes and their disposal	*Hong Kong*: Advice on movement of used EEE, 2011. Legislative control on used EEE

it to the developed countries (Pathak et al., 2017). Among the major destination countries in Asia (China, India, and Pakistan), the domination of informal and private players are a major bottleneck to inventoried the E-waste in these countries (Abbas, 2010; Jain, 2010; Kurian, 2007). Although these countries have a lower labor costs, the large rate of E-waste generation (through both import and domestic production), the transportation cost, and above all the costlier technology for its benign disposal, presents hurdles despite the enactment of environmental regulations. Henceforth, the informal sector keeps growing to handle the majority of E-waste in developing countries.

4.3.2 Socio-economic factors of defendants

The socio-economic factors play vital role in building up policies on E-waste. It is highly dependents on the materials' market price, its weight therein the product, volume of E-waste generation and recycling rate along with the cost of recycling and purity of the recovered material, and environmental benignness of the process (Cucchiella et al., 2015). The recycling of E-waste has been found economic feasible (Azevedo et al., 2017); however, the contribution by the informal sector to the major steps of collection, screening, and treatment causes serious issues on environment and human health. In developing countries, the rag pickers are unavoidable part of recycling practices but practicing without safety measurements. For the sake of little benefits, their life is put in danger. Hence, the earning by these malpractices cannot be allowed on a larger benefit of the society and demands for a sustainable recycling practice through the regulatory bodies.

4.3.3 Environmental consequences

E-waste is a complex mixture of several heavy and hazardous metals (including Cu, Fe, Ni, Co, Pb, Cd, Cr, Au, Ag, and Pd) along with the plastics and ceramics whose composition changes with its manufacturing time (Robinson, 2009). Plenty available studies on the contamination caused by E-waste to the soil, water, and air at recycling or landfill sites have established the hazardous and toxic nature of E-waste (Borthakur and Singh, 2017; Williams, 2011). Moreover, the malpractices by informal recycling is making the situation worst in the developing countries like Nigeria, India, Ghana, China, Thailand, Vietnam, Pakistan, Indonesia, and Bangladesh. The open burning of wire piles, melting of circuit boards, and discard of metal bearing acidic solutions are in usual practice (Borthakur and Singh, 2017). The concentrations of hazardous organic compounds polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) have found to be increased in the air and water and show adverse impact on environment and human health (refer Table 4.4). Through which, it reaches to our food chain and directly affecting the human health (Tue et al., 2014, 2016; Luo et al., 2011).

4.4 Proposed sustainable E-waste management in developing countries

Reverse logistics has been actively implemented to bring sustainability in the developed countries, which is now followed by the developing countries. Three major steps of the reverse logistic for E-waste recycling are (Tsydenova and Bengtsson, 2011) as below.

Table 4.4 Environmental and health consequences due to E-waste recycling (Chen et al., 2011; Ilankoon et al., 2018; Pathak et al., 2017).

Pollutants	Sources	Environmental consequences	Health impact
Pb	PC monitors, batteries, PCBs, light bulbs, lamps	Degrade the soil fertility	Can cause intellectual impairment in children, anemia, and kidney damage
Cd	Rechargeable computer batteries, older CRTs, PCBs, Ni-Cd batteries, infrared detectors, semiconductor chips, ink or toner photocopying machines, and mobile phones	Highly toxic and bioaccumulation occurs in the environment	Affects kidneys and bones, reproductive damage, and lung emphysema
Be	Power supply boxes, computers, x-ray machines, and ceramic components of electronics	Adverse impact on environment	Affect liver, kidneys, heart, nervous system, lymphatic system, and develop beryllium sensitization
Hg	Lighting devices for flat screen displays, CRTs, PCBs, thermostats, monitors, and cold cathode fluorescent lamps	Contaminant soil, air, and water, and bioaccumulation occurs	Damage the central nervous system, anemia, and kidney damage
Cr	Production of metal housings (anticorrosion coatings), data tapes, and floppy disks	Highly toxic, causes severe water pollution	Carcinogens, affects the reproductive and endocrine functions
Ba	CRTs (2%–9% Ba), fluorescent lamps	Get accumulated in soil, water, and plants	Low blood potassium, cardiac arrhythmias, respiratory failure, dysfunction, and paralysis

(*Continued*)

Table 4.4 (Continued)

Pollutants	Sources	Environmental consequences	Health impact
POPs	Used in circuit boards, plastic casings of computers, lubricants and coolants in generators, fluorescent lighting, ceiling fans, electric motors, connectors, and mobile	Bioaccumulation in the environment (very resistant to break down) and air pollution	Neurotoxicity, long-term exposure can lead to impaired learning and memory functions interfere with thyroid and estrogen hormone systems
PVC	For insulation on wires and cables	Incineration produces chlorinated dioxins and furans, which are highly toxic even in very low concentrations, persist long in the environment	Cause pulmonary dysfunctions and lung damage

1. Disassembly: Selective disassembly target hazardous or valuable components for special treatment.
2. Upgrading: Mechanical processing and/or metallurgical processing to increase the content of desirable materials.
3. Refining: purifying the recovered materials using chemical (metallurgical) processing to make them acceptable for the original use.

On the other hand, developing countries are struggling to cover all recommended steps of recycling and disposal due to the limited availability of infrastructure, technological access, and investments. Henceforth, implementation of Best-of-2-Worlds (Bo2W) principle that provides a network and pragmatic solution for E-waste treatment can boost the emerging economies in developing countries (Nnorom and Osibanjo, 2008). Fig. 4.2 depicts the installation for collection center and screening center by municipalities based on the number of inhabitants. It looks for technical and logistic integration of best preprocessing in the developing countries to dismantle E-waste manually and best end-processing to treat hazardous and complex fractions in international state-of-the-art end-processing facilities. Besides, environment cleaner production design, EPR, standards and labeling, product stewardship, recycling, and remanufacturing are some of the good practices adopted by various countries to deal with the E-waste caused problems and bringing up the sustainability (Azevedo et al., 2017). These practices inspire the government/nongovernmental organizations, researchers, and academicians to propose the sustainable some models for E-waste management.

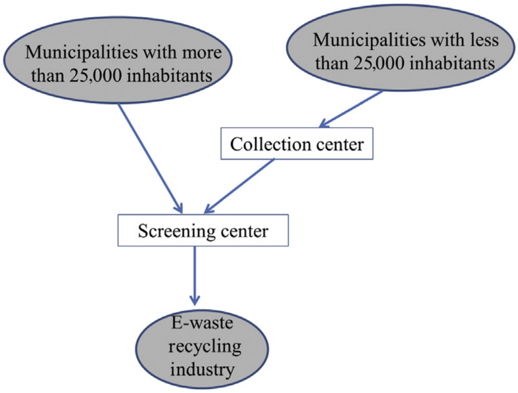

Figure 4.2 Proposed model for government guidelines, collection center (cc), and screening center (sc) (Azevedo et al., 2017).

4.4.1 Proposed mathematical model

Most of the developing countries have the potential to utilize and manage the EEE/UEEE and generated E-waste. Several sustainable and mathematical models have been proposed in this direction (Azevedo et al., 2017; Pathak et al., 2017). 3-R representing the "reduce-reuse-recycle" model for E-waste management (Habib et al., 2015; Parajuly et al., 2017), while for specifying the need and importance of recycling Pathak et al. (2017) have presented a schematic flow of EEE and E-waste (as shown in Fig. 4.3). The description of each process is given in Table 4.5. The flow of the model indicates a positive effect of proper collection and recycling that mitigating the global environmental impacts. However, based on the present scenario of developing countries, a quick shift from informal to formal sector is not easy, therefore formal sector alone cannot display the desired result and indicating for they work together in an integrative manner.

4.4.2 Circular economy

The circular economy is another concept which is able to slow down the rate of EEE consumption by circulating them within the system for the longest possible time and minimizing/eliminating the E-waste generation through smarter product design and business model (Parajuly et al., 2017). It is also involved multi-R system (including reduce, reuse, refuse, recycle, recovery, rethinking, and redesign) that emphasize the social, environmental, and economic aspects (https://www.unido.org/sites/default/files/2017-07/Circular_Economy_UNIDO_0.pdf). The circular economy principle is embedded in the Indian E-waste management rule 2016 and also fulfill the requirement of sustainable development goals of UNIDO 2015. The concept of a circular economy in E-waste management is shown in Fig. 4.4. However, various barriers like technological advancements, poor collection system, need for finance and involvement of private sector, training to the informal sector, the

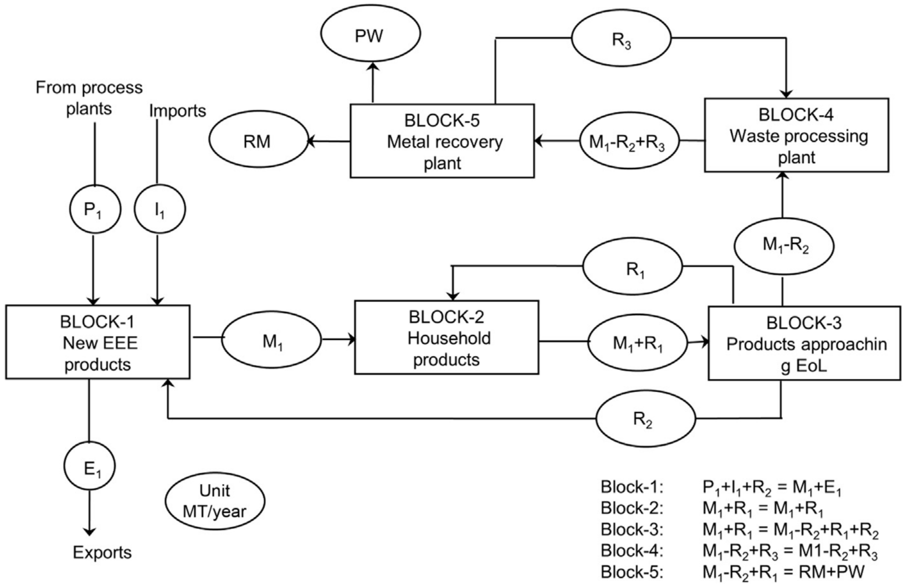

Figure 4.3 Sustainable management model for electrical and electronic equipments (Pathak et al., 2017).

Table 4.5 Estimation of sustainability for E-waste recycling in India, contributed by the formal and informal sectors (Pathak et al., 2017).

Process	Description
Block-1	New EEE product comes to the market
Block-2	Household used product
Block-3	Products approaching EoL
Block-4	Waste processing plant
Block-5	Metal recovery plant
E_1	Exported EEE
I_1	Imported EEE
M_1	New EEE
M_2	EoL completed EEE
R_1	EEE with uncompleted EoL to be reused
R_2	Consumer sending the unused EEE to second hand market
R_3	Metal recycling (formal and informal) of WEEE
RM	Recovered metals
PW	Potential waste

volatile market for recovered materials through the recycling of E-waste have been identified by different researchers (Balde et al., 2017). Keeping in view, it is recommended that the informal sector especially rag pickers should get advance training for collection, dismantlers, and refurbishers, provide incentives and financial support to

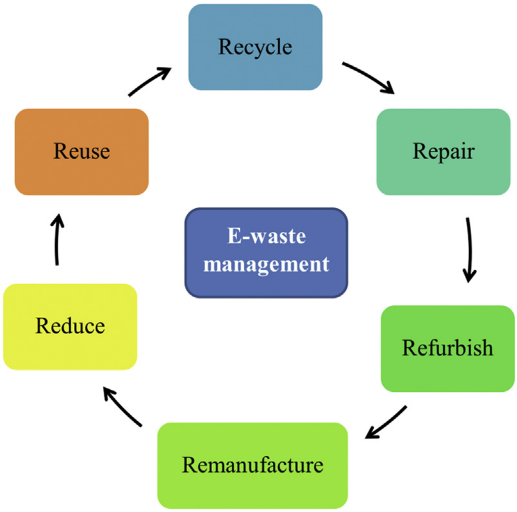

Figure 4.4 Circular economy for E-waste.

attract private sector participation, strict regulations for E-waste imports, monitoring and enforcement of existing regulations, international collaborations, and decentralized E-waste repair/refurbish initiatives. This initiative can be a panacea to build the sustainable E-waste model.

4.5 Conclusions

E-waste is a greater challenge for the sustainability of developing countries, which receives the larger part of this hazards from the developed countries. It is much needed that the developing countries follow the legislative frameworks of developed countries to enact the E-waste specific policies and try to effectively manage this problem of the globe. The control of E-waste flow mostly in the name of UEEE needs an urgent call as the developing countries themselves are generating more domestic E-waste than developed countries. This problem in countries like China, India, Pakistan, Nigeria, Brazil, and Argentina is more serious because a good share of the economy depends on the informal business of E-waste. The discussed cases and current scenario of the E-waste management system and policies of these countries tells about the growing awareness in this field but it is very slow. Only a few developing countries could yet able to establish their own E-waste policy. However, several models on the sustainable management of E-waste have been given but as per the current scenario, negligence of the informal sector is not possible. It has been analyzed that a significant reduction in the E-waste disposal can be obtained in near future only if formal and informal sectors work together to practice an integrative recycling and this practice may lead toward the circular economy.

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