Chapter 5

Environmental Management of E-waste

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1 E-waste and the Global Scenario

1.1 Defining E-waste

Electronic (E-) waste commonly refers to whitegoods, information and communication technology (ICT) hardware, business and household electrical and electronic items, that have completed its useful life and are discarded. Some known definitions of E-waste are as follows:

- It can be classified as any electrical powered appliance that has reached its end of life (EoL) (Sinha-Khetriwal, 2002).
- A broader and growing range of the electronic devices ranging from large household items to personal computers that have been discarded after their EoL (Puckett et al., 2002).
- The multifarious combination of ferrous, nonferrous, ceramic, and plastic materials (The Association of Plastics Manufacturers in Europe, APME, 1995).

Nevertheless the terms E-waste and WEEE (waste electronic and electrical equipment) have been frequently used synonymously because of the increasing use of electronics in electrical equipment; Indeed, E-waste can be seen as a subset of WEEE: discarded electronic goods (e.g., personal computers, hand/telephones) belong to the E-waste category, while WEEE additionally refers to the EoL electrical appliances (e.g., air conditioners, washing machines, refrigerators). In the most formal way, the European Commission has defined WEEE as wide-ranging EoL commodities, that can be used to generate, measure and transfer electric/electromagnetic current, or can be functionalized by supplying the electrical current during their service life (EU RoHS Directive 2002/95/EC, 2003).

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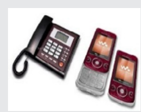
TABLE 1 Categories of E-waste as per Their Applications and Size

Description	Example
Heat and temperature exchanger equipment, includes refrigerators, air conditioners, heat pumps	
Display screen and monitors, includes computers, laptops, televisions, notebooks and tablets	
Electric lamps, includes fluorescent, high intensity discharge and LED lamps	
Large size equipment, includes electric stoves, washing machines, Xerox machines, photovoltaic panels	
Small size equipment, includes household items such as microwaves, toasters, vacuum cleaner, electric kettles, calculators, video cameras, electrical toys, and small medical devices	
Small ICT equipment, includes mobile phones and landline telephones, routers, table printers, global positioning systems, personal computers	

As there does not seem to be a standard definition for E-waste, WEEE and E-waste have been accounted for the same in the Indian legislation for E-waste management (E-Waste Rules, 2011). In this chapter, we use the term “E-waste” to refer to all the discarded/broken/surplus/obsolete electrical and electronic devices, as stated by Pathak et al. (2017). More specifically, E-waste can be divided into six categories (Balde et al., 2015), as shown in Table 1.

1.2 Global Generation of E-waste

The worldwide growth of electrical and electronic products has affected the modes of communication, transportation, entertainment, education, and health-care, and ultimately generates a large amount of E-waste that is discarded periodically. A United Nations University report, “The Global E-waste Monitor Report 2017,” revealed that the amounts of E-waste generated has reached to a new height of 44.7 million metric tons (MMT) in 2016 (Balde et al., 2017), and is estimated to reach a record of approximately 50 MMT in 2018, fuelling concerns about the sustainable management of E-waste equivalent to ~5% of the entire solid waste generated worldwide (Kiddee et al., 2013).

Traditionally, the developed world such as the United States and the leading countries of Europe has been considered the main manufacturers and generators of the E-waste (Robinson, 2009). This scenario is changing very quickly, and currently China is leading the global list of E-waste generator countries (7.2 MMT/year), leaving the United States in second place. The contribution of another fast-developing country, India, is also increasing and supposed to overtake Japan by 2020 for the third rank in global E-waste generation. The top 10 global countries generating E-waste by 2016 (as total amount of generation and per capita consumption) is shown in Fig. 1.

Of all the regions, Asia is generating the most at 18.2 MMT E-waste (~41%), followed by the United States (~29%), and Europe (~27%) (E-Waste, the Escalation of a Global Crisis Report, 2014). The gap in E-waste generation between the developed and developing countries is very wide. The richest country is generating 19.6 kg/inhabitant compared to the poorest country generating only 0.6 kg/inhabitant.

The major segments of the E-waste items (generated in 2016, 44.7 MMT) are 16.8 MMT small equipment, 9.1 MMT large equipment, 7.6 MMT of temperature exchange (freezing and cooling) equipment, 6.6 MMT of screens and monitors, 3.9 MMT of small ICT and 0.7 MMT of electric lamps (E-Waste Recycling Facts and Figures, 2018). Even though the annual growth rate of E-waste generated per category differs, the overall amount is expected to be grow in coming years. As can be seen from Fig. 2, the E-waste category of temperature exchangers, and the large and small equipment will have the highest

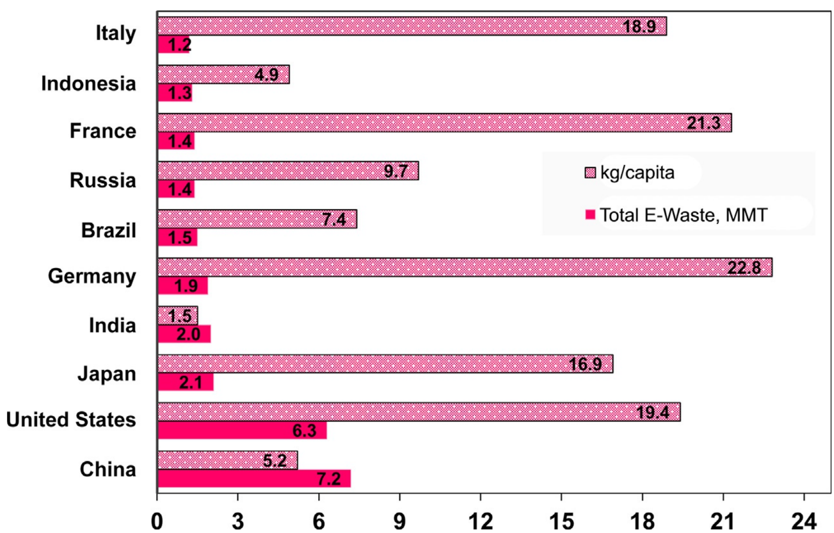


FIG. 1 The amount of E-waste generation: top 10 countries in the year 2016.

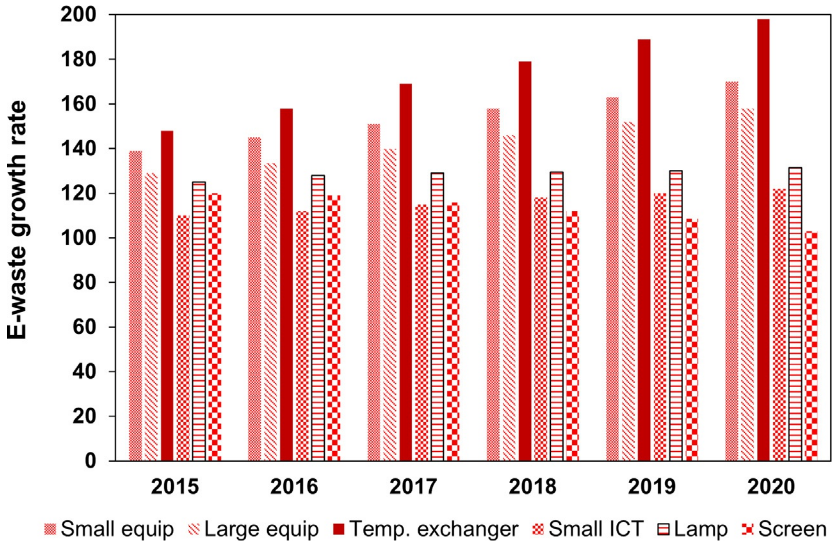


FIG. 2 Categorical growth rate of E-waste worldwide.

growth rates due to their rising consumption by the rapid urbanization and improved living standards worldwide. However, E-waste of screens will decline due to the replacement of heavier cathode ray tubes (CRTs) with flat panel displays; whereas, the effects of miniaturization will cause a slower growth of ICT waste.

1.3 Quantification of E-waste

The global trade and transport of discarded EoL electrical and electronic equipment from developed to developing region, either as used items (including by the means of charity) or in the form of E-waste, has received considerable attention. To keep an effective eye on the environmental management of E-waste in a sustainable manner, the correct quantification of E-waste generation is important. Without these statistics it is difficult to estimate the fate and transport of contaminants and resultant emissions. For example, the import of polybrominated diphenyl ethers (commonly used as retardants) in China has exceeded the domestic manufacturing of brominated flame retardants by 3.5-fold (Guan et al., 2007). Currently, E-waste is mainly generated by the countries belonging to the Organization for Economic Cooperation and Development (OECD). However, E-waste from developing countries is estimated to double in the next 6–8 years. Hence, a consistent mass balance of the global E-waste generation and their movement from OECD to non-OECD countries is vital. The total amount (EW_{Net}) of E-waste with domestic generation (EW_{Gen}),

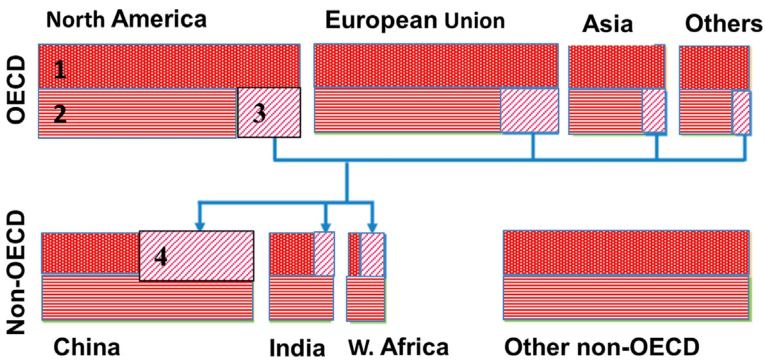


FIG. 3 The global E-waste mass balance, where the width of each box scales according to the contributed amount of E-waste (1, EW_{Gen}; 2, EW_{Net}; 3, EW_{Exp}; 4, EW_{Imp}).

amount of imports (EW_{Imp}), and exports (EW_{Exp}) processed yearly in a particular country can be calculated as:

$$EW_{Net} = EW_{Gen} + EW_{Imp} - EW_{Exp} \tag{1}$$

Based on the abovementioned descriptions, Breivik et al. (2014) presented the global mass balance of E-waste as shown in Fig. 3.

In India, the E-waste generation is likely to grow exponentially by 2025, based upon the scattered quantitative data that is available. Pathak et al. (2017) adopted a predictive model and quantified the two most sellable electronic goods, mobile phones and computers. For this, the items were inventoried with real-time available data on the weight and production number, and their total weight was determined with respect to the increasing population of country, and the decreasing trend in average weight. Notably, the average weight of PCs reduced from 6 kg (in 2005) to only 3 kg (in 2015), and it decreased for mobile phones from 180 g (in 2001) to 110 g (in 2009). The amount of E-waste generation (EW_{total}) has been calculated as follows:

$$EW_{total} = \frac{(\text{Average mass of E} - \text{waste}) - (\text{Number of the items produced})}{\text{Average life of the product}} \tag{2}$$

By considering an average life of 3.0 and 2.2 years for computers and mobile phones, respectively, the obtained quantity is presented in Fig. 4 with ±5% error on the prediction data (Pathak et al., 2017). The modeled data clearly depicts that the problem of E-waste in India will keep rising in near future.

2 Challenges Posed to the Environment

Waste is one of the prominent environmental management issues that is increasing with the pace of world population and consumption. E-waste is a new

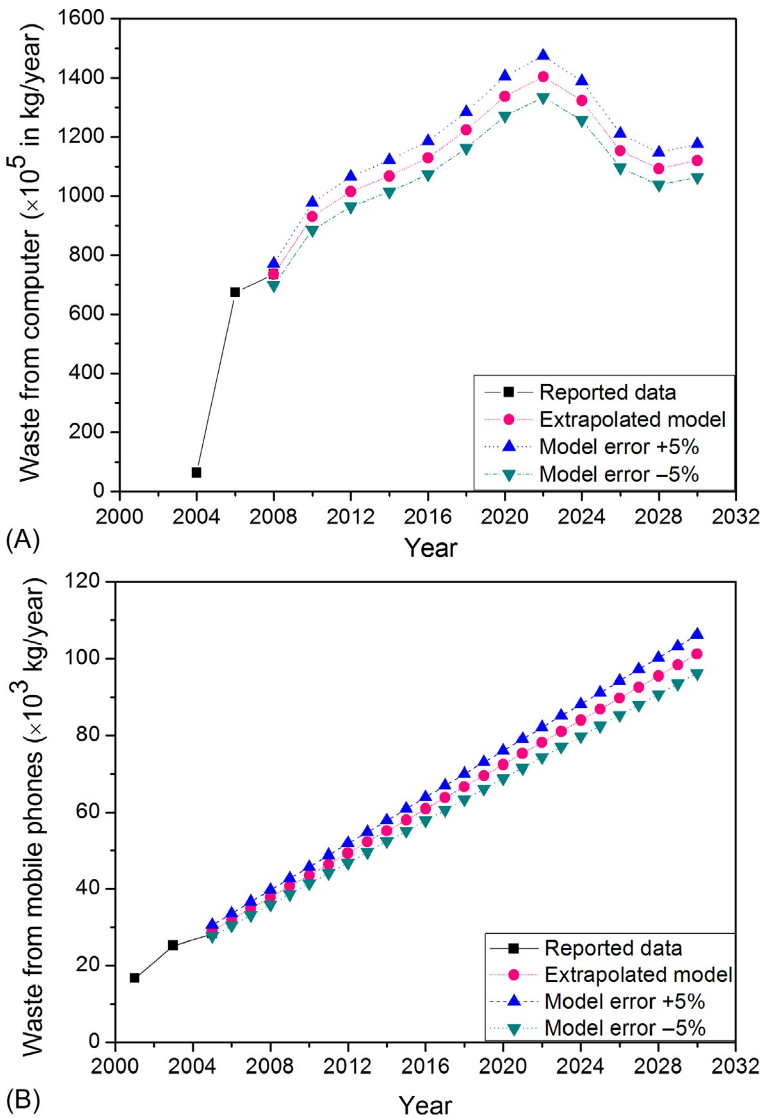


FIG. 4 The generation of (A) computers and (B) mobile phones in India as predicted by the mathematical modeling (with ±5% extrapolation).

worldwide challenge and has become an environmental scourge to be battled. The regulations on E-waste disposal into land, water, and air have become more stringent, thus the cost of their effective management has increased as well and the hazardous material has become a subject of trade. Approximately 15% of the European Union's trade is that of waste (Bisschop, 2014; IMPEL-TFS, 2006). Developing countries with a rapid growth rate such as China and India are not only the biggest producers of E-waste but are also seen as the dumping ground for global E-waste trade (Pathak et al., 2017; Zeng et al., 2017). The lack of treatment facilities, the recycling of valuable secondary materials for use in the processing country, and cheaper operating costs for waste transfer are the major causes for the movement of E-waste. Consequently, determining the challenges posed to the environment and public health for their sustainable management is very important.

2.1 A Lethal Weapon Destroying the Environmental Sustainability

An ideal scenario for sustainability can be if the E-waste treatment is performed at the place of its generation. However, with E-waste, due the to above mentioned reasons, it is being transported from one site to another. The developed countries, being aware of the health and environmental hazards caused by E-waste, prefer to trade it to developing countries where cheap labor availability makes their processing low-cost, albeit without knowing the effects on human health and high risks to biota (Pathak et al., 2017). A large range of toxic chemicals, heavy metals, and polyhalogenated organics released from E-waste are very harmful. Reports on the problems due to the E-waste in developing countries and the countries in transition, indicate that India, China, Indonesia, Cambodia, Pakistan, Thailand, and African countries receive E-waste from developed countries for reuse and disposal, dismantling, and recycling purposes (Czuczwa and Hites, 1984; Robinson, 2009; Williams et al., 2008; Wong et al., 2007). The unsafe, unscientific, and informal procedures are causing social and human health problems and serious risks to the environment (see Section 2.2). The leaching of heavy metals toxicity and spillage of chronic chemical pollutants contaminating soil, water, and organics into the air is dangerous to the environmental sustainability that can be lethal to the biota, as described in Table 2 (Pathak et al., 2017).

TABLE 2 Toxicity and Their Impact on Public Health Associated With the Substances Present in E-waste

E-waste Components	Toxic Metals	Limit (ppm)	Disease Caused by the Exposure to Above Permissible Limit
Ceramic capacitors, switches, batteries	Ag[a]	5.0	Excessive amount causing blue pigments on body, damages brain, lung, liver, kidney
Gallium arsenide is used in light emitting	As[b]	5.0	Chronic effect and causes skin disease and lung cancer and impaired nerve signaling

Continued

TABLE 2 Toxicity and Their Impact on Public Health Associated With the Substances Present in E-waste—cont'd

E-waste Components	Toxic Metals	Limit (ppm)	Disease Caused by the Exposure to Above Permissible Limit
Electron tube, lubricant, fluorescent lamp, CRT gun	Ba[b]	<100	Causes brain swelling, muscle weakness, damage to the heart
Power supply boxes, motherboards	Be[b]	0.75	Causes lung cancer, beryllicosis, skin disease, carcinogens
PCBs, casing, PVC cables	Br[b]	0.1	thyroid gland damage, hormonal issues, skin disorder, DNA damages, hearing loss
PCBs, battery, CRTs, semiconductors, infrared detectors, printer ink, toners	Cd[b]	1.0	Pose a risk of irreversible impacts on human health particularly the kidney
Printed circuit boards	CN[b]	<0.5	Cyanide poisoning, >2.5 ppm may cause to coma and death
Plastic computer hosing, cabling, hard discs, as a colorant in pigments	Cr(VI)[b]	5.0	Toxic in the environment, causing DNA damage and permanent eye impairment
Batteries, LCD, switches, backlight bulbs or lamps	Hg[b]	0.2	Damages brain, kidney and fetuses
Mobile, telephone, batteries	Li[a]	<10[d]	Diarrhea, vomiting, drowsiness, muscular weakness
Batteries, semiconductor, CRT, PCB	Ni[a]	20.0	Causes allergic reaction, bronchitis, reduces lung function, lung cancers
Transistor, LED lead-acid battery, solder, CRT, PCBs, florescent tubes	Pb[c]	5.0	Damages brain, nervous system, kidney, and reproductive system, causes acute and chronic effects on human health
CRT glass, plastic computer housing and a solder alloy	Sb[b]	<0.5	Carcinogen, causing stomach pain, vomiting, diarrhea and stomach ulcer
Fax machine, photoelectric cells	Se[b]	1.0	High concentration causes selenosis

TABLE 2 Toxicity and Their Impact on Public Health Associated With the Substances Present in E-waste—cont'd

E-waste Components	Toxic Metals	Limit (ppm)	Disease Caused by the Exposure to Above Permissible Limit
CRT, batteries	Sr[c]	1.5	Somatic as well the genetic changes due to this cancer in bone, nose, lungs, skin
Batteries, luminous substances	Zn[b]	250.0	Nausea, vomiting, pain, cramps, and diarrhea
Cooling units and insulation foam	CFCs[b]	<1.0 for 8 h/day	Impacts on the ozone layer which can lead to greater incidence of skin cancer
Transformer, capacitor, condensers	PCBs[b]	5.0	PCB causes cancer in animals and can lead to liver damage in humans
Monitors, keyboard, cabling, and plastic computer housing	PVC[b]	0.03	Hazardous and toxic air contaminants, release of HCl causes respiratory problems

[a]*Critical.*
[b]*Hazardous and toxic.*
[c]*Radioactive waste.*
[d]*Limit in serum/blood.*

2.2 Direct and Indirect Impacts on Environment and Human Health

Improper management of E-waste has both direct and indirect impacts on the environment and human health. Informal recycling of E-waste is usually practiced using unsafe methods and these unscientific practices have a direct impact. Some cases of informal recycling practices in different parts of India will be accounted here to illustrate this direct impact. It has been noticed that Mandoli industrial area of Delhi-National Capital Region has created acute environmental problems and serious threats to human health (Pathak et al., 2017). Analysis of geomaterials (i.e., soil and water) revealed that the concentrations of hazardous and heavy metals are much higher than that of the accepted levels. It is very likely that leaching of metals in soil (As = 17.08 mg/kg, Cd = 1.29 mg/kg, Cu = 115.50 mg/kg, Pb = 2,645.31 mg/kg, Se = 12.67 mg/kg, and Zn = 776.84 mg/kg) are contaminating the ground water reservoir of nearby areas, causing environmental geo-hazards and health problems (Pradhan and Kumar, 2014). Additionally, the concentration of organochlorine compounds, the most hazardous substances, have been found up to 7 mg/kg in the soil close to recycling areas (Ha et al., 2009). Another case of severe pollution was observed in Moradabad, Uttar Pradesh by the dioxins and furans due to printed circuit boards (PCBs) being burnt in an open environment. Improper disposal of burnt ashes containing high amounts of poly-carbons and heavy metals, directly thrown into the river Ramganga (a subsidiary of the Ganga), has also caused acute water pollution (Centre for Science and Environment, 2015). Moreover, the situation in a slum area at Bangalore was more critical, as there were some cases of cyanide leaching from attempts to recover the precious metals from E-waste (Ha et al., 2009). Cyanidation is most effective process for gold extraction; however it needs to maintain an alkaline pH throughout the leaching due to its pK_a value $= 9.5$. Below that, it forms toxic HCN gas whose exposure >500 ppb has much adverse impact on human health. Unscientific practices and the discharge of cyanide effluent stream without treatment has contaminated the ground water and soil. A 247-fold higher lead content leached in ground water, and an elevated amount of trace metals (Cu, Zn, In, Sn, Pb, Hg, Bi, etc.) mixed with air due to open burning of E-waste has been recognized as nonsustainable practices (Sepulveda et al., 2010). A higher concentration of Cu, Sb, Bi, Cd, and Ag in the workers' hair and blood samples is a direct evidence of the adversity caused by improper recycling of E-waste.

Furthermore, the constituents in E-waste fluctuate according to the produced goods/devices and contain more than 1000 diverse substances, many of which fall under the hazardous and radioactive waste category (see Table 2). The consequences are mainly physical health outcomes, for example, dysfunction of lungs, thyroid, the nervous system and fertility in mammals (Agrawal et al., 2012; Sepulveda et al., 2010). It has been observed that environmentally-friendly disposal techniques are quite expensive and not well communicated to local refurbishers in India; therefore in most of the cases, disposal jobs are practiced by rudimentary techniques. The E-waste cycle states a negative impact of improper handling of E-waste (shown in Fig. 5), emphasizing their sustainable management. Landfilling of E-waste releases the toxic and heavy metals that can eventually drain to pollute the ground water (Kiddee et al., 2013).

The cadmium content in one mobile phone battery can pollute 600 m^3 water. The PCB and other plastic components of electronic appliances are highly flammable, upon burning it releases acute toxic gaseous dioxins and furans that threatens vital components of the ecosystem (Awasthi et al., 2017; Wang et al., 2005). A large amount of heavy and toxic metals leached from landfill are adsorbed into the soil, changing the physiochemical properties, and contaminate the water resources. The suspended particulates released into the environment during the dismantling and shredding process causing atmospheric pollution. An increase of particulate matter in the ambient air causes breathing difficulties, eye and respiratory irritation, coughing, choking, pneumonitis, tremors, and neuropsychiatric problems for humans. Unsafe incineration of

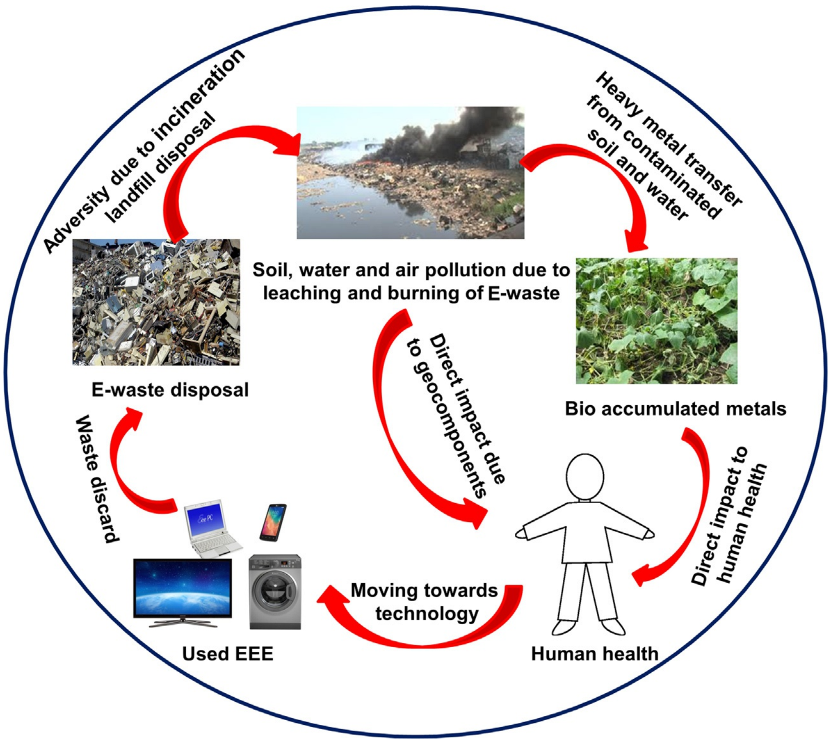


FIG. 5 Direct and indirect impacts on the environment and humans.

E-waste releases several toxic and hazardous substances (organic and inorganic components) responsible for the air pollution.

Pollution and contamination causing impacts in other forms can be referred to as indirect impacts. For example, vegetables and fruit grown in the contaminated soils and irrigated by polluted water (containing heavy metals and organic substances therein) can easily absorb the pollutants. When those foods/vegetable/fruits are harvested the pollutants enter the human body through an indirect route, however they have the same adverse effects as direct contamination. The direct and direct impacts of the E-waste cycle are shown in Fig. 5.

Moreover, improper management/recycling of E-waste causes the loss of valuable metals therein, and hence, a requires virgin metals from their primary source. Consequently, the mining-to-metal recovery process will be required again. For example, the production of approximately 100% of the indium, 72% of the ruthenium, 50% of the tin, 44% of the copper, 34% of the silver, and 22% of the mercury mined globally every year causes severe environmental impact (Zeng et al., 2017). The recovery of concentrated metals from E-waste instead of mining their primary source can save approximately 41% energy costs of mining and reduce water consumption by 391.5 m^3/kg of the metals in ore milling. This ultimately decreases the environmental pollution generated by the energy intensive process and large amounts of wastewater generation with contaminants. Notably, an average of 10 million mobile phones contains 160 ton of copper, 3500 kg silver, 340 kg gold and 150 kg palladium.

3 Management and Legal Framework for Managing E-waste

Managing E-waste by using legal frameworks can mitigate environmental issues both at the global and regional levels. The worldwide statistics indicate that approximately 66% of population is at present covered by E-waste legislations and have legal authority to manage their E-waste (Balde et al., 2017). Globally, approximately 50 MMT E-waste will be generated in 2018 but only 20% of that may go through formal recycling processes under legislative norms. As stated in Section 1.2, the generation of E-waste is rapidly increasing and it requires correct inventorization and management. However, developing and under developed countries are still struggling to set proper guidelines for E-waste generation. In addition, E-waste that is managed through illegal trading routes, mainly handled by the informal/unauthorized sector, is difficult to inventorized and becomes a threat to sustainability. Therefore, a sound legislation is required to coordinate the formal collection and recycling of E-waste. A few of the legislative components needed for legislation are mentioned in Fig. 6.

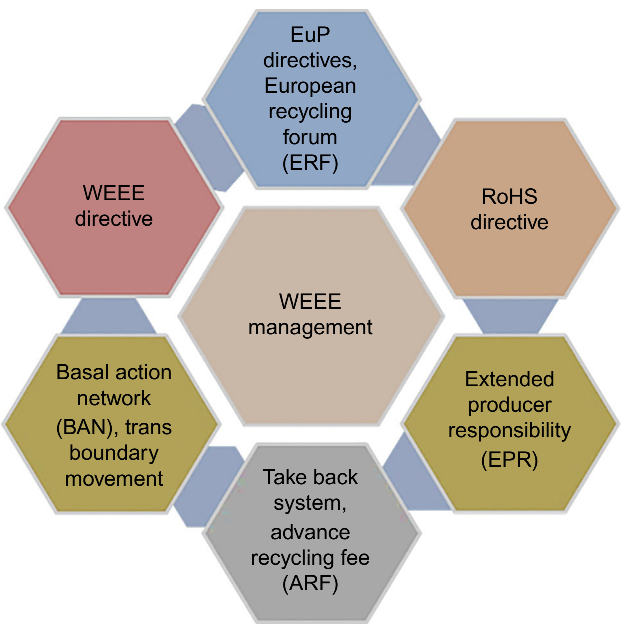


FIG. 6 Legislative components for E-waste.

Sections 3.1 and 3.2 state the legislative norms for developing and developed countries.

3.1 Restriction on Trans-Boundary Movement

Global initiatives has been undertaken on E-waste management to restrict its transboundary movement, either by countries developing their own methods of management or adopting the initiatives of others. Table 3 presents some of the prominent legislation/regulation developed by leading countries for sound E-waste management within their legislative boundary (Pathak et al., 2017).

It is clear that the awareness of global community for the sustainable handling of E-waste is increasing with time; however, no specific guidelines or legislation has been developed or adopted to tackle it for the developing/underdeveloped countries that are becoming dumping yards for the waste from developed countries. The policy paralysis for the import and efficient management of E-waste, expansion of the used EEE (UEEE) market with a rise in lower-middle class economy, growing upper-middle class economy with rapid industrialization, and growth of the unauthorized recycling sector have remained the main factors to proliferate E-waste in developing countries and dramatically increased the

TABLE 3 Global Initiatives for the Management and Legal Framework of E-waste

Country/ Region	Legislation/Regulation	Description
South Korea	Act on the control of transboundary movement of hazardous wastes and their disposal, 1994	Restriction on export without consent from the importing country
Belgium	Directive 2002/96/EC on WEEE, 2002	The Public Waste Agency of Flanders controls the waste management and responsibility of producer
Finland	Government Decree on WEEE, 2004	Export prohibited out of the EU unless exporter prove that reuse and/or, recycling will be practiced as directed in this Decree
France, Germany and the Netherlands	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

Continued

TABLE 3 Global Initiatives for the Management and Legal Framework of E-waste—cont'd

Country/ Region	Legislation/Regulation	Description
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
China	Catalogue of restricted imports of solid wastes, 2008	Restriction on junk electrochemical products and electrical wires mainly for copper recycling
Norway	The revised EU directives, 2006	A WEEE register established with mandatory membership for every producer and importer of an approved take-back company
The United Kingdom	Under EU directives in 2007	Adopted the EU directives
Thailand	Criterion for import of used EEE (UEEE), 2007	Control on the classified UEEE
Singapore	Import and export of E-wastes and used electronic equipment, 2008	Approval on the movement of hazardous E-waste on case-to-case basis
Pakistan	Import policy order, 2009	Banned the import of refrigerator, and air conditioners, CRT can be imported only with used computers
The United States	HR 2284: Responsible electronics recycling act, 2011	Banned the export of WEEE item: PCs, TVs, printers, Xerox, phones, CRTs, batteries, items containing Pb, Cd, Hg, Cr, Be, and organic solvents
Hong Kong	Advice on movement of UEEE, 2011	Legislative control on UEEE
Nigeria	Guide for importers of UEEE into Nigeria, 2011	Import of WEEE banned with a compulsory registration of importers

problem. The E-waste movement in other forms (such as charity, secondhand market, concentrates and scraps, etc.) also needs to be controlled as the vast population of growing middle-class in the developing countries are providing a big market of UEEE and refurbished items (in many cases even after reaching their EoL).

3.2 Regional/National Initiatives for Managing E-waste

The WEEE Directive announced by EU in 2003 incorporated extended producer responsibility (EPR) as a basic principle was not only followed by the EU member states but also by those outside the European area. All initiatives have ensured the compatibility of EPR with their own domestic regulations, needed to ensure any regulations adopted from outside countries will have similar outcomes. Therefore it is imperative to understand some of the leading models such as Japan and South Korea that were followed by others. Japan divides their E-waste in two different categories as per the practices of their consumers of electronic goods and is guided by two separate laws (Chung and Suzuki, 2008). The Law for the Promotion of Effective Utilization of Resources (LPUR) deals with recycling of personal computers and small size secondary batteries. The Law for the Recycling of Specified Home Appliances (LRHA) deals with EoL TVs, refrigerators, washing machines and air conditioners by imposing certain responsibilities for retailers, manufacturers and consumers (http://www.pc3r.jp/home/recycle_flow.html). The transportation cost to discard home appliances is borne by the consumer, or after payment upon request the retailer is obliged to take back the used items. Under LRHA, the municipal areas do not have any obligation for collecting home appliances; however they can do so by charging the transportation and recycling fees to the retailers and consumers. The effectiveness of the LRHA was challenged when it was found that approximately half of the EoL computers and home appliances had been exported to other Asian countries (Shinkuma and Huong, 2009; Yoshida and Terazono, 2010) mainly to avoid the payment for transportation and recycling cost. Hence, the idea of pre-payment instead of postpayment charging for the recycling costs has arisen (Shinkuma and Huong, 2009; Ongondo et al., 2011).

South Korea is one of the leading countries in waste management (including E-waste) by imposing the Law for Promotion of Resources Saving and Reutilization (LRSR) in 1992, with an aim of environmental protection and resources conservation (Hyunmyung and Yong-Chul, 2006). In 1996, South Korea joined the OECD and in January 2003 launched the Producer Recycling system (PRS) (Chung and Suzuki, 2008) to increase the obligation of E-waste recycling on the manufacturing end, with computers, phones, printers, Xerox and fax machines included in the list of items (Park, 2005). The Korea Environment and Resource Corporation (ENVICO) has the responsibility for the entire monitoring of system, for example, shipment records of each manufacturer, the recycling process and levying the recycling charge (ENVICO, 2006). An Eco-assurance system was introduced in 2008 for systematic management of EEE and automobile waste from the product design to disposal stage

TABLE 4 Major Milestones for E-waste Management Legislation in India

Milestones	Indian Legislations	Significant Facts
1st	Environmental Protection Act, 1986	Discussed all sorts of pollution in the environment
2nd	Hazardous (Management and Handling) Act, 1989	States the hazardous waste definitions, rules for management and handling of hazardous waste
3rd	Hazardous (Management and Handling) Act, 1989; 2000; 2003	Classified hazardous waste category into 12 types
4th	Hazardous (Management, Handling and Transboundary Movement) Act, 2008	Introduced transboundary movement into the rule
5th	E-waste (Management and Handling) Rules, 2010; 2011	Introduced notification on E-waste legislation, commencement of E-waste legislation with EPR guidelines and incorporated all suggestions made in 2010
6th	E-waste (Management) Rules, 2016	Fixed responsibility of refurbishers and manufacturers

(https://www.keco.or.kr/en/core/operation_eco/contentsid/1978/index.do). The system has gained popularity due to the distributed obligations in a practical manner being the responsibility of government administration and local bodies instead of the producers and consumers. Since 2012, recycling centers in the different parts of Korea have been operationalized under the National Recycling Network.

Among the developing countries, India is the fifth-largest generator of E-waste but it took a long time to prepare a clear legislative framework on E-waste management (as can be seen in Table 4).

Initially, all types of pollution were nominated in the Environmental Protection Act 1986 without specific mentioning of E-waste. It was a provincial government of the State of Maharashtra who took the initiative along with the International Resource Group Systems of South Asia Pvt. Ltd. (IRGSSA) for a separate legislation on E-waste management (MPCB, 2007). This effort was because Maharashtra was an industrial hub in the postglobalization era of India, and was estimated to generate 20,270 ton E-waste (in 2005) with proper plan for handling the waste (E-Waste Rajyasabha Report, 2011). The Government of Maharashtra took the issue to the Union Government of India and demanded a proper E-waste management, which was kept under the

Hazardous Waste Act 1989, 2000, and 2003 (The Gazette of India, No. 465, 28/7/1989, 2016). Likewise, the transboundary movement (TBM) was introduced into the Hazardous Act under the umbrella of the Basal Convention, further amendments being made in 2008. The diversity in E-waste composition (i.e., hazardous and nonhazardous substances) demanded that separate collection, treatment, and disposal needed specific guidelines/regulation in India. Thereafter the E-waste management and handling rule notification was emanated in 2010 under the sections 6, 8, and 25 of the Environment (Protection) Act 1986. It clearly described the responsibility of producers, dealers, collection centers, refurbishers, dismantlers, recyclers, auctioneers, and bulk consumers involved in the manufacturing, sales, purchasing, and processing of EEE or components as stated in schedule-I of the E-waste Legislation Notification 2010. Within the next 60 days of the notice period, the Ministry of Environment and Forest (E-Waste Rules, 2011) received several suggestions and objections from the local people and industries, and then by incorporating EPR with other valuable suggestions, a full-fledged Act was introduced in May 2011. Notably, the EPR was introduced for the first time ever in an Indian legislation to provide a scientific approach for handling solid waste. An EPR system is supposed to provide a comprehensive policy package to extend the responsibility onto producers to deliver the EoL products for their treatment by policy instruments through subsidies, fees, bans, standards, and information campaigns. However, the societal structural of India with a large population of lower-to-middle income groups has enlarged the gray market for UEEE (sometimes even after the EoL). Treatment of waste generated by this means was not addressed in the E-Waste Rule 2011, and therefore, a further amendment was made to reintroduce E-waste management in 2016 (E-Waste Management Rules, 2016). This rule has incorporated the responsibility of manufacturers and refurbishers with several aspects, for example, EPR management, and provides an overall information and strategy from the collection to recycling of E-waste in an eco-friendly manner (Pathak et al., 2017).

3.3 Recycling of Generated Waste

Recycling of E-waste is a postconsumer operation. The benefits of E-waste recycling are to:

- reduce the absolute amount of waste disposal.
- recover the valuable metals from E-waste.

Unfortunately, the recovery of metals by recycling of E-waste is a complex situation and is largely (~90%) practiced by the informal sector, and requires effective and organized recycling programs. The gaps between the formal and informal recycling of E-waste can be depicted in the world's two largest processing countries of China and India (shown in Table 5). The unscientific

TABLE 5 Comparing the Gaps Between the Formal and Informal Recycling

Formal Recycling		Informal Recycling	
Separating the CRT components in closed chamber through heating, crushing done by shredder machine	Separated glass sold to known TV manufacturers, proper extraction system for phosphorus removal is safer for workers	Manual processing of CRTs for separating the glass and metal components	Refurbished CRTs sold to nonbranded TV manufacturer, separated glass sold to bangle makers (in India), inhaling phosphorus is very toxic and causes health problems to the workers
Waste PCBs are processed through shredding, machining, pyrolysis, smelting/leaching for recovery of valuable and precious metals	Smelting in closed system and pyrolysis are safer	Manual sorting, dismantling, and separation by burning the PCBs followed by soaking in acid in open air	Releasing toxic organic and acid fumes and heavy metals, generation of polluting effluents
High capital cost	Dismantling unit, smelter and gas scrubbers are costly	Low cost investment	Mostly illegal investment without government scanning

and unsafe practices of the informal recycling poses serious threat to the environment and human health (as discussed previously). Often, burning in the open air, sorting and dismantling in a small room, the use of toxic chemicals for retrieving precious metals and consequent discard of effluent without adequate treatment are in practice without any safeguards.

A United Nations study on quantification of the EoL recycling rates has shown a major concern of only 5%–10% recycling of valuable metals from E-waste, and identified some barriers to the effective recycling of E-waste (Izatt et al., 2014). Small amounts of profitable metals (other than Cu, Al, and Fe), the lack of economic incentive, a complex mixture of metals/alloy, scarce collection of EoL items and their higher cost, improper design for dismantling/recycling, and lack of public awareness are the major reasons for the ineffective recycling of E-waste. Similar points including the absence of

E-waste-specific legislation are valid for the prevalence of informal recycling sectors. Looking across the global platform, the Basel Convention agreement seems to be losing the battle and only succeeds in a partial fulfilment of halting the informal recycling methodology (Williams et al., 2008). Although the United States supports the ban, it was not a signatory to it, and does not have a consistent policy to prevent the export of E-waste to non-OECD countries (Ongondo et al., 2011). Due to such reasons, the thriving states for informal recycling in China and India are the continuous supply of E-waste through the illegal imports from OECD countries. Additionally, the domestic individual collections, low processing costs through the use of pollutive methods, and maximized recovery of functional value by cheap manual separation are also contributory factors.

Nevertheless, global initiatives in recent times have increased formal recycling. A process flow diagram for E-waste recycling used by one of the organized recyclers at Maharashtra (in western India) is shown in Fig. 7.

Fig. 7 shows that the dismantling of E-waste collected by different modes is segregated into six types before further processing. The dismantled E-waste is shredded in a four-shaft shredder machine (capacity 3000 kg/h) and passed through a magnetic separation of iron that separates the nonmagnetic metals along a moving conveyor belt. Plastic components are collected and sold to authorized buyers. Components such as PCBs are directly treated for precious

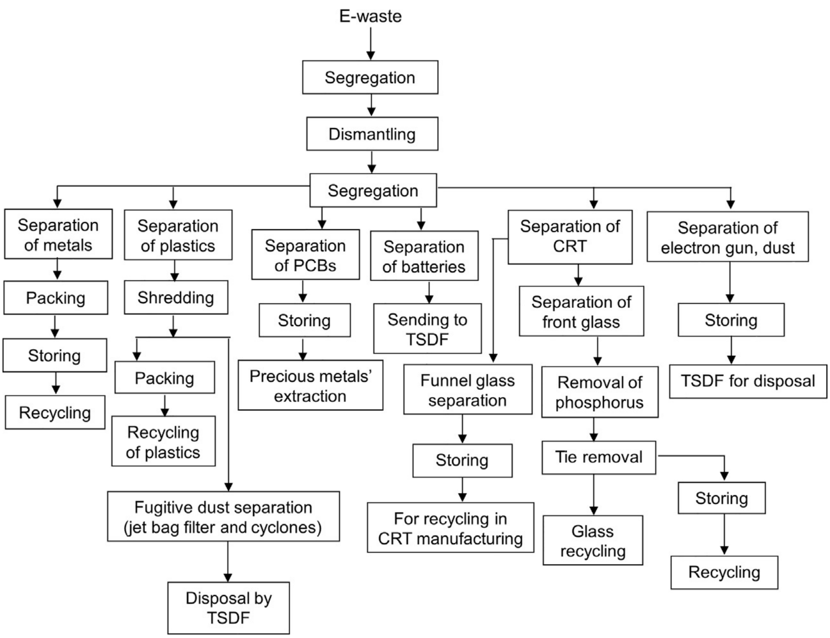


FIG. 7 Steps for formal recycling of E-waste.

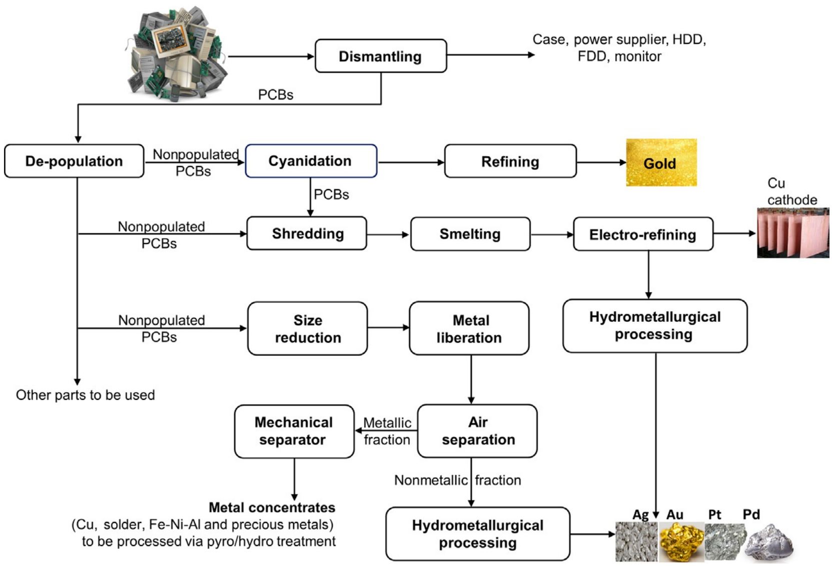


FIG. 8 Recovery of precious metals from PCBs.

metal recovery by pyro/hydrometallurgical processing routes. Recycling of CRTs follows operations such as cutting, shredding, shadow mask removal, crushing, washing, and re-melting of the crushed/fused glass (cullet). The surface-coated layer of the panel and funnel needs an acid and alkaline wash, however drum washing has been recognized as ecofriendly equipment for this operation. The glass sludge obtained as a secondary waste of this process is also being recycled. The glass-to-glass recycling of CRTs is not beneficial, and therefore after separating and sorting of the funnel glass and removal of phosphorus from the front glass, recycling is directly performed by the CRT manufacturer. The company claims that recovery of the hazardous elements such as Hg by their recycling facility is 99.9%. Some of the hazardous wastes such as electron guns are sent to authorized treatment units for their final disposal under the norms of the pollution control board.

The interests of formal recyclers are well known in the recovery of the valuable (Cu, Ni, Co) and precious metals (Au, Ag, Pt, Pd, Rh) from the PCBs of PCs and mobile phones, whose common processing schemes depicted by Pathak et al. (2017) is shown in Fig. 8. The key of PCB recycling related to the economic and technological arena of metal recovery. The shredded PDBs (size 5 mm) are fed to Cu/Pb smelter in a fixed quantity mixed with the fresh ore/concentrate charge for the recovery of copper and precious metals. The composition of Cu (~30 wt%) is used with the precious metals in the common downstream processing of electrolytic Cu-production. However, the process disadvantages of air pollution, losses of Zn, Sn, Pb and noble metals have given

TABLE 6 Reduction of Greenhouse Gases in Metals Recycling Process

Resources Recovery (×1000 ton)		CO_2 Reduction on Recycling (×1000 ton)	
Ferrous metal	404	Refrigerators	256
Nonferrous metals	37	Washing machines	196
Plastics	180	Televisions	100
Others	93	Air-conditioned	16
Total	720	Total	620

rise to mechanical pretreatment in combination with the hydrometallurgical recovery of precious metals (as shown in Fig. 8).

In Table 6, the performance of E-waste recycling to reduce greenhouse gases is presented in Table 6 (Pathak et al., 2017). In recent years, the selective recovery of copper over precious metals has been claimed at up to 95% by using ammonia-based leaching and a subsequent leaching in sulfuric acid. The search for the application of greener reagents is also ongoing which can give more sustainability to the recycling process, nevertheless this has yet to be adopted in wide commercial applications.

4 Role of Different Stakeholders in Environmental Management of E-waste

Life-cycle assessment (LCA) is a major key to understanding the complete flow of EEE and clearly define the role of each stakeholder in achieving environmental sustainability for E-waste management. Assuming the closed-loop value

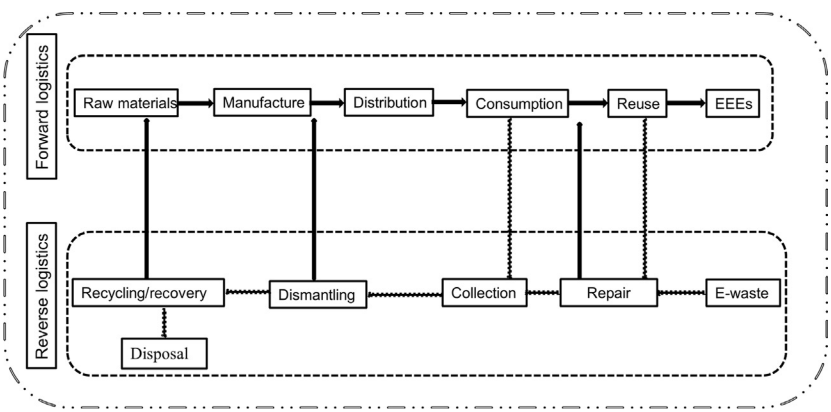


FIG. 9 The closed-loop supply chain of EEE and E-waste or WE.

chains as given in Fig. 9 an organized study should be undertaken using the LCA. Under the closed-loop system, much of the E-waste can be refurbished, reused, or sent back to manufacturers to create new products; whereas, many components of E-waste can be either recovered using mechanical treatment or incinerated. Use of ecofriendly substances in production of new EEEs can be promising in avoiding the release of hazardous substances into the environment and mitigate the public health risk. Minimization of EEE consumption with a simultaneous increase of their life would be the best forward-logistics step. In developing countries with huge populations such as China and India, the reverse flow of EEEs is a large problem. The E-Waste Management Rule (2016) of India is solely based on the "extended producer responsibility" (EPR), but the Administrative Measure on Pollution Prevention of E-waste in China is mainly based on the "polluter pays" principle. In the following sections we discuss the most influential actors in that process (https://www.uncclearn.org/sites/default/files/inventory/integrated_weee_management_and_disposal-395429-normal-e.pdf).

4.1 Producers

Comprehensive management of E-waste and its disposal is one of the prime responsibilities of EEE producers. The other roles of producers are: obeying the set legal guidelines for EEE items that may cause environmental damage via improper treatment, itemizing an individual product's composition and the way of treatment after reaching to their EoL, and driving awareness programs among the consumers/users about prohibition against E-waste disposal with the household items. Introduction of new ecodesign standards to enhance the life and efficiency of product, refurbish the used EEEs, and their recycling are also the important responsibilities of producers. In this context, establishing E-waste collection centers that are accessible to consumers, ensuring their appropriate management at all stages such as collection, transportation, storage, refurbishment, treatment, recycling, resources recovery, and final disposal along with the cost-bearing of selective collection and waste management, are tasks to be performed by the EEE producers. The producer's responsibilities on environmental management of E-waste were discussed in Section 3.2.

4.2 Consumers

The role of a consumer/user is fundamental as it is they who decides either to purchase a new product or exchange an item. Most of the time, users remain unaware to the fact that switching to a new product or technology is contributing to E-waste generation. Hence, they have the responsibility to select the correct product and use them to the full extent of product's life. Users should realize that the generated E-waste can be recycled or reused within the value chain, and hence, products that comply with environmental standards promoting their reuse and extension of lifecycle should be purchased. The role of consumers is also vital in tracking waste, and awareness of waste segmentation can ensure that items are not discarded with other business/household waste. Scavenging is a major issue in developing countries for environmental friendly processing of E-waste. The user community can instead opt for established collection centers by producers/governing bodies/local administration that can assist in solving the scavenging problem.

4.3 Recyclers

As stated previously, the role of recyclers is utmost important, and they are primarily responsible for the environmental management of E-waste throughout the closed-loop value chain as well as their final disposal. The role of recyclers (practicing either formal or informal recycling) is associated with functions performed at each of the stages of E-waste management: collection, sorting, dismantling, treatment by various means, recovery of valuable substances, and the final disposal of the processed mass. The increasing price of critical and valuable metals in the E-waste makes it lucrative for the illegal export of E-waste from developed to developing countries. However, the recyclers should meet the environmental norms, and technical and quality standards to establish a proper recycling of E-waste. However, in informal recycling, these factors are surpassed by a focus only on profit-making schemes. Unscientific recycling practices by recyclers often cause severe damage to the environment, and therefore must be formalized and approved as a timely requirement. The recyclers should ensure proper management procedures for maintaining the standard quality of the recycled product, and meet the current environmental regulations and identify the associated risks of E-waste management, for example, environmental pollution and illegal exports. Meanwhile, LCA can be a key component for assessing the E-waste recycling that covers information on collection to recovery. Although there is integrated E-waste management combining the formal and informal sectors which aims to yield the maximum recycling rates and mitigation of environmental concerns, the lack of sound technologies has led to a weak performance for both resource recycling and environmental improvements.

4.4 Statutory Bodies

The statutory bodies constituted by the national/state governments can act as a binder for all the stakeholders and combine their active engagements in environmental management of E-waste. They can establish laws for practicing the EPR and determining obligations to manage the EoL products. They can play a vital role in encouraging users to reuse EEE before disposing, inform consumers on the correct procedures for disposal, create awareness of the health and environmental hazards due to E-waste disposal, and the designated

TABLE 7 Stakeholders and Their Defined Roles in the Swiss E-waste Management System

Stakeholders	Roles and Responsibilities
Federal government	Supervising the entire system and initiations for basic guidelines/ regulations
Producers/ importers	Managing and tracking day-by-day operations of the system
Distributers/ retailers	Supporting the affairs of producers/importers
Consumers	Returning discarded EoL products to collectors/retailers
Collectors	Collections of E-waste, safe storage, and preventing illegal marketing
Recyclers	Follow the guidelines on environmental friendly recycling of E-waste with minimum emissions and concerning on employees health and surrounding biotic

collection centers. The statutory bodies can devise policies for E-waste management by considering the key aspects of following:

- Regulatory frameworks based upon EPR in combination with the obligations and rights of each stakeholders; proper actions can be taken against those whodo not comply with the obligations.
- Actions and awareness programs on health and environment in collaboration with the public and private sectors, civil societies, and other nonprofit organizations.
- Promoting the collection, refurbishment, and recycling practices by formal sectors.
- Effective measures to prevent illegal marketing of E-waste and its unaccounted donations to nongovernmental organizations.
- Research and design promotion policies that help the integral management of E-waste, innovative recycling process, and reduction of E-waste volume.

Switzerland was the first country to establish a formal E-waste management system. A nonprofit organization, the Swiss Foundation for Waste Management (SENS), established in 1990, was operating on behalf of the manufacturers/ importers/retailers for recycling the refrigerators and freezers. Thereafter in 1998, an Ordinance on the return and the disposal of electrical and electronic appliances (ORDEA) came into existence, and today the coverage area of SENS has spread to a full range of household appliances, electrical toys, mobile phones, electrical tools, and lighting equipment. A typical role of each stakeholder in the E-waste management system (from top to bottom), as defined by the Swiss statutory body is given in Table 7.

5 Perspectives

Surveying the problems associated with E-waste reserves, existing legal frameworks, and the future of worldwide market trends of advanced EEE, it is clear that the most important action would be the effective implementation of legislation. Developing countries should not be permitted to dump waste by nominating it as charity donations, and there should be strict rules for NGOs to not accept the donations of UEEE from the outside countries. If anyone was found to violate such guidelines, the government/regulatory agencies should ensure strict actions against the defaulter/s. Educating consumers in their steps for sustainable management of E-waste is a challenging task, but can be done via utilizing media sources such as newspapers, TV, social media sites, and by awareness campaigns. The involvement of public offices such as the municipal corporations in metropolitan cities, municipalities/notified area committees in small town/cities, and village committees (such as Gram Panchayats in rural India) can provide strength to these practices and providing space for collection centers. The collected E-waste can be directly sent to the formal recycling centers that have government authorization.

5.1 Need for International Standards

Efficient E-waste management requires a structured process from collection to final disposal after formal recycling, including a clear understanding of the EEE's lifecycle. The technical standards facilitating the E-waste management can be vital for the actors of the management system in the absence of specific legal framework. Individual companies and/or countries can learn from past experience to improve their management processes by using the technical standards as reference guidelines.

Some of the international standards and rules belonging to different countries can be taken as the reference guidelines, as given in Table 8. For example EPR has been introduced in India through the E-Waste Rule 2016. However, an inclusive EPR system (with advance recycling and disposal fee) can be implemented effectively where the additional fee will be imposed onto the producers and consumers during the sale of products for raising the recycling facilities and bearing the cost of final disposal. Subsidizing the collection-to-recycling operations, fixing the obligations on manufacturers, tracking the sales records for UEEE, and controlling the gray market are necessary, along with proving the basic infrastructural facilities and incentives for designing greener products. A government can offer more incentives and tax benefits to those companies having an effective disposal and/or recycling mechanism. However, in spite

TABLE 8 International Legislation in Different Countries

Country/ Region	Legislation/Regulation	Description
South Korea	Act on the control of trans-boundary movement of hazardous wastes and their disposal, 1994	Restriction on export without consent from the importing country
Belgium	Directive 2002/96/EC on WEEE, 2002	The Public Waste Agency of Flanders controls the waste management and responsibility of producer
Finland	Government Decree on WEEE, 2004	Export prohibited out of the EU unless exporter prove that reuse and/or, recycling will be practiced as directed in this Decree
France, Germany and the Netherlands	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
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
China	Catalogue of restricted imports of solid wastes, 2008	Restriction on junk electrochemical products and electrical wires mainly for copper recycling
Norway	Revised EU Directives, 2006	A WEEE register established with mandatory membership for every producer and importer of an approved take-back company
The United Kingdom	Under EU Directives in 2007	Adopted the EU directives

TABLE 8 International Legislation in Different Countries—cont'd

Country/ Region	Legislation/Regulation	Description
Thailand	Criterion for import of used EEE (UEEE), 2007	Control on the classified used EEE
Singapore	Import and export of E-waste and used electronic equipment, 2008	Approval on the movement of hazardous E-waste on a case-to-case basis
Pakistan	Import policy order, 2009	Banned the import of refrigerator, and air conditioners, CRT can be imported only with used computers
The United States	HR 2284: Responsible electronics recycling act, 2011	Banned the export of WEEE item: PCs, TVs, printers, Xerox, phones, CRTs, batteries, items containing Pb, Cd, Hg, Cr, Be, and organic solvents
Hong Kong	Advice on movement of UEEE, 2011	Legislative control on used EEE
Nigeria	Guide for importers of UEEE into Nigeria, 2011	Import of WEEE banned with a compulsory registration of importers
India	E-waste management rule, 2011; 2016	Legislative control on E-waste and used EEE

of several efforts to develop a consensus on international standards, there are still no technical standards in global use.

5.2 Turning Challenges Into Opportunity

As discussed earlier, the challenges for the environmental management of E-waste can also provide several positive opportunities. The generation of green jobs in the future, transboundary transfer of technology worldwide, a capacity build-up for E-waste management, revenue generation by the recovery of valuable and precious metals from E-waste, and improvement in the quality of peoples' lives are some of the main opportunities that can be tapped by an efficient E-waste management. The UNEP has indicated a requirement for urgent preparation of the increasing E-waste reserves in developing countries with emphasis on correct collection and recycling for the recovery of economically-attractive metals, to protect the public health of the population, and the emergence of a new green economy (UNEP, 2013).

Reclamation of metal values from E-waste has attracted recyclers as a source of good income which has the potential to create more jobs in future by the formal sector. A synergized system with returned deposit is feasible. During the analysis of the management system, a significant reduction in waste to landfill can be obtained in the near future by achieving a proper formal-to-informal recycling ratio at the earliest possible opportunity.

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