Chapter 8
E-Waste Management from Macroscopic to Microscopic Scale

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Abstract Increased demand for electrical and electronic equipment as well as a reduction in the end of life of most electrical products has led to the generation of large amount of E-waste. These wastes contain both beneficial and hazardous components. Therefore, there should be proper management of E-waste in order to protect man and the environment. In this review, we addressed the various categories deployed towards effective E-waste management such as collection and disposal of dangerous portions and recovery of precious metals and energy. The benefits, challenges and future of E-waste management were also highlighted.

Keywords E-waste · Recycling · A printed wiring board · Precious metals · Material flow analysis · Life cycle assessment · Metallurgy · Heavy metals · Plastic · Extended producer responsibility

8.1 Introduction

Implications of Uncontrolled Management of Waste Electronics
A lot of E-waste components are generated in many countries mostly in low- and middle-income households, and these E-wastes are often disposed into wild landfills. In some of these countries, including Nigeria, Ghana, India, Pakistan, China and the Philippines, E-wastes are dismantled using simple equipment to retrieve vital metals by unexpected and untrained persons without much consideration for environmental and public health (Ikhlayel 2018). In these countries, E-waste salvaging predominantly involves processes such as burning of wires in open spaces to retrieve copper from the interior while confiscating the plastic part, also the extraction of precious metals such as silver, gold and platinum from printed wiring boards.

Many reports in the literature have outlined the components of E-wastes which are known toxicants that have deleterious effects on human health. These toxicants including heavy metals and polychlorinated biphenyls (PCBs) have been shown to be rampant in sediments, air and aquatic biotas in regions where E-wastes abound. The negative effects of these toxicants on organisms range from acute effects, endocrine disruption, reproductive dysfunction and cancer (Zhang et al. 2014).

The management of electronic and electrical wastes (E-waste) in various regions of the world has received tremendous attention recently owing to the already established negative eco-impact(s) of these very hazardous waste materials. Several studies done in relation to E-waste management have shown that E-waste(s) management seems to be region-specific as many countries have implemented varied policies to check the rampaging of these wastes materials in that region (Townsend 2011).

The transboundary movement of E-waste from developed countries to developing countries has been a major issue of concern for a long time (Townsend 2011). There is still a great deal of work as regards E-waste management in developing countries. However, the opposite can be said in the case of developed nations

(Ikhlayel 2018). There are still arguments that E-waste generation in some developing countries does not call for urgent attention because of the lesser quantity and longer half-life of electronic goods in those countries due to financial constraints, on both local community and national scales (Kiddee et al. 2013).

In some developed countries, E-wastes have been treated or disposed of by landfill or by informal incineration as in the case of some developing countries. However, technological innovations and recycling methods have been developed for regional and global E-waste management (Zeng et al. 2015). In order to avert public debate, the cost of disposing of E-waste must be balanced against the environmental benefit (Zhang et al. 2014).

Different options for managing electronic-wastes ranging from the microscopic to the macroscopic outlook are discussed. However, it is necessary to note that the method governing regulatory structure in a region and the already established management options in a region are major factors that influence the choice of option for managing E-waste.

8.1.1 Macroscopic Management of E-Waste

8.1.1.1 The Role of Government in E-Waste Management

Opportunities obtainable for handling E-wastes depend greatly on location and existing governing regulatory structure (Townsend 2011). Different legislations (e.g. the Basel Convention) with regard to E-waste have been enacted to check the wider issues concerning E-waste management.

Compared to the more advanced countries, the state of affairs regarding E-waste is even more of a threat in the developing world. In order to curb this menace, most of the developed world and several countries in the developing world have endorsed legislation to check unlawful trafficking and unlicensed recycling of E-waste. These legislations appeal the extended producer responsibility concept based on life cycle considerations in the hope that it will provide inhibition as well as a remedy (Premalatha et al. 2014).

Laws and policies regarding the appropriate management of E-wastes continue to advance with time (Ramesh Babu et al. 2007). However, such policy designs should be innovative and should be strictly enforced in order to exert its efficacy (Lu et al. 2015). In the aspect of promulgating and then implementing E-waste regulations, the European Union and some Asian countries have been described as frontiers. Meanwhile, the Swiss are ascribed with founding the first comprehensive E-waste management system, covering collection to disposal (Sthiannopkao and Wong 2013).

Laws and guidelines have been enacted by the European Union to restrict the use of materials in electrical and electronic equipment which are detrimental to human health and environmental safety (Directive 2002/95/EC, the RoHs Directive). Guidelines were also stipulated on the promotion of E-waste recycling and collection processes (Directive 2002/96/EC, the WEEE Directive). These guidelines also include steps for the creation of ‘collection scheme’ for users of ‘electrical and electronic’ gadgets to deposit their wastes without payment. This is targeted towards increasing E-waste collection, recycling and/or reuse (Zhang et al. 2015).

Upon the end of life (EoL), the strategy used in managing E-wastes depends on the following:

- Applicable regulations and policies already in place (e.g. disposal bans, recycling bans)
- Existing infrastructure for handling such materials (e.g. availability of take-back centres, collection opportunities)
- Consumers’ understanding of and attitudes towards these programs, policies and opportunities (Townsend 2011)

Apart from government interference and legislation, a lot of non-governmental bodies and individual groups have been involved in E-waste clean up; however, in most parts of the world, much success has not been attained (Premalatha et al. 2014).

Funding researches on E-waste management should be encouraged and adequately sponsored by private and government agencies. This will encourage more researchers to focus on this area, leading to novel ideas and technologies for effective E-waste collection and handling systems (Lu et al. 2015).

To achieve an efficient E-waste handling system, there is the need for active participation of all sectors involved, not just the manufacturers, distributors/suppliers and end-users but also those who collect, recycle or reuse waste items. This is to ensure that adequate and economical protocols are applied to equipment management and subsequent E-waste reuse and disposal (Tansel 2017).

8.1.1.2 The Role of Consumers in E-Waste Management

The awareness and behaviour of consumers towards the proper management of E-wastes are two key factors in any effective E-waste management strategy (Borthakur and Govind 2017). The socioeconomic profile of consumers, such as gender, age, income and education level, plays key roles in the behaviour or willingness of the general public to participate in managing E-wastes (Yin et al. 2014). Consumers of e-products also have a role to play in ameliorating the burden of E-waste in the environment. Consumers can minimize E-waste accumulation by:

- Using only necessary e-gadgets
- Efficient use of electrical/electronic equipment in order to extend the shelf life
- Purchasing items with very minor or zero E-wastes
- Avoiding addiction and dependency on electrical/electronic gadgets
- Being informed on the long-term negative impact of E-waste on the environment
- Pro-actively taking measures to achieve and maintain zero E-waste accumulation

Heightened public awareness concerning wastes such as E-wastes may create a possibility that consumers would be willing to pay some costs associated with recycling these waste materials. Payments could be in the form of prepaid deposit or incorporated into the product fee prior to the purchase of the equipment (Yin et al. 2014). In order to encourage public participation in the management of E-wastes, training sections and workshops should be organized, developed and publicized both in the form of television programs and newsletters, in order to further enlighten the public on steps to manage and contain E-waste. These activities can serve as a common playground for stakeholders to reinforce their mutual understanding, trust and respect, which will become a solid groundwork for a further partnership in the field of E-waste management (Lu et al. 2015).

During these programs, the awareness of the high environmental and health risks associated with improper handling of these wastes should be created and adequate remedies propagated for future purposes.

8.1.1.3 Extended Producer Responsibility

Extended producer responsibility (EPR) can be defined as an environmental protection strategy that makes the producer of a product responsible for the entire life cycle of the product and especially for the take-back, recycling and final disposal of the product (Mascarenhas et al. 2016).

EPR imposes manufacturers of electric and electronic equipment with the task of retrieving and recycling their products as soon as it reaches its end of life. The EPR serves as a strategy of saddling manufacturers (rather than the society) of electronic products with the responsibility of bearing the costs associated with managing, recycling and disposing of a particular product (Jaiswal et al. 2015). Since disposal of E-waste, without any obligation on their importer and unauthorized recycler with improper technology, can promote the transboundary flow of these E-wastes, EPR comes in as a strategy to check this menace (Pathak et al. 2017).

EPR was established with backing for the polluter pay principle and the acknowledgement of the importance of improving the management and recycling of waste as agreed at the Rio Earth Summit in 1992 (Nnorom and Osibanjo 2008a, b). The policy instruments introduced under EPR include various types of product fees and taxes, e.g. advance recycling fees (ARFs), product take-back mandates, virgin material taxes, and their combinations. Also included are pay-as-you-throw, waste collection charges, and landfill bans (Pathak et al. 2017).

EPR aims at achieving the following goals:

- Developing electrical and electronic equipment with a ‘green’ approach and hence constrained the use of components that are hazardous to the environment
- Retraction of products after their end of life as a take-back process
- Recycling and reutilizing of used up products in order to control the generation of E-waste

Although EPR plays an imperative role in defining the tasks and duties associated with E-waste recycling, it does not imply that the burden of E-waste recycling should be left to the manufacturers alone. The alliance and coordination of multi-stakeholders is also a vital element of EPR. Therefore, the government, manufacturers, sellers, mobile telecom carriers, professional recovery operators and consumers should all partake in E-waste recycling (Yin et al. 2014). There is also need for others such as consulting bodies, investment firms and experienced personnel in various localities to collaborate towards ensuring the widespread application of green E-waste treatment technologies by providing capital support and management expertise (Lu et al. 2015).

8.1.2 Mesoscopic Management of E-Waste

The mesoscopic strategy of E-waste is a proactive instead of reactive measure used to effectively manage E-waste. The mesoscopic approaches to E-waste management include material compatibility analysis, life cycle assessment (LCA), material flow analysis (MFA), and multicriteria analysis (MCA).

8.1.2.1 Material Compatibility Analysis

Material compatibility analysis is important to determine if the production chemicals are compatible with the materials of construction of the chemical storage, chemical delivery and production systems (Zeng et al. 2017). This includes both metallic and non-metallic materials.

8.1.2.2 Material Flow Analysis of E-Waste

Several studies have demonstrated the essence of material flow analysis (MFA) as a veritable tool in the management of E-waste. This analysis reveals the genesis to exodus (i.e. reuse, storage, recycling and deposit in landfills) of electronic products (Ikhlayel 2018). MFA is a tool that aims at detailing the route of materials (such as E-wastes) flowing into recycling sites, or disposal areas and stocks of materials, in space and time. MFA links sources, pathways and the intermediate and final termini of the material (Kiddee et al. 2013).

MFA considers the flow of E-waste and its concomitant evaluation in terms of environmental, economic and social values. This analysis is carried out using software-based simulations (Singh 2016). For a successful implementation of MFA, data availability is vital (Kahhat and Williams 2012). Accurate MFA of E-wastes is hindered by a deficiency of accurate data on the quantity of E-waste in a given economy owing to the fact that no record exists for E-waste products in the national statistics of goods produced, sold and traded in (Lau et al. 2013). To a degree, the issue of deficient data can be circumvented by construction using the principle of mass balance (Kahhat and Williams 2012). Hence implementing an inclusive approach in assembling data for MFA could help minimize environmental hazards and maximizing potential resources in a particular system (Agamuthu et al. 2015).

A primary step to be taken for the successful MFA for E-wastes in any country is the creation of an inventory of E-wastes in that region. To accurately do this, sales data (obtained during production, importation, exportation), stock data or quantity of equipment currently in use (determined from households using these devices and/or workplaces where E-waste can be found) and the average lifetime of the items (this depends on the behaviour of each consumer) are required (Lau et al. 2013).

8.1.2.3 Life Cycle Assessment of E-Waste

Life cycle assessment (LCA) can be defined as a systematic strategy that can be used to assess and quantify the environmental performance associated with the various phases of a product creation, processes and activities (Hong et al. 2015). LCA also finds application in defining many environment impact(s) categories such as carcinogens, climate change, the ozone layer, ecotoxicity, acidification, eutrophication and land use, to improve the environmental performance of products (Kiddee et al. 2013).

LCA has also been used to design eco-friendly electronic devices and to curtail E-waste problems (Kiddee et al. 2013). LCA can also be used to systematically evaluate and identify environmental inventory, impact, key factors, decisions, optimization and improvement opportunities associated with all stages of system boundary concurrently (Hong et al. 2015).

LCA can be used to recognize latent environmental impacts to develop eco-design products such as printers, desktop personal computers, heating and air conditioner devices, washing machines and toys.

8.1.2.4 Multicriteria Analysis of E-Waste

Multicriteria analysis (MCA) is a decision-making device developed for considering tactical decisions and resolving multifaceted multicriteria problems that include qualitative/quantitative aspects of the problem (Kiddee et al. 2013). MCA decision-making tool can be used by decision-makers to discover the most appropriate portfolio that consists of multiple measures for overcoming the barriers in the way of sustainable E-waste management under the conditions of uncertainty and incomplete information (An et al. 2015).

8.1.3 Microscopic Management of E-Waste

8.1.3.1 Recycling of E-Waste to Recover Valuable Materials

Improved standard of living of citizens, fast economic growth and enhanced technological advancement has resulted in the production of a large amount of electrical and electronic equipment (Lu and Xu 2016). The useful life of electronic and electrical equipment has been reduced over the years owing to the adjustment of consumer taste and technological innovations (Khaliq et al. 2014). This has led to the accumulation of the resultant waste electrical and electronic equipment (WEEE) or E-waste in the environment (Khaliq et al. 2014; Lekka et al. 2015; Akcil et al. 2015; Cayumil et al. 2016; Heydarian et al. 2018). Within this waste stream, the major interests are the printed wiring boards and the plastics (Lu and Xu 2016). Besides environmental concerns, recycling of this waste is attractive and also viable since it contains significant amounts of precious metals (Cayumil et al. 2016; Ebin and Isik 2016). The presence of precious metals such as palladium, platinum, gold, tantalum, selenium, etc., in E-waste, makes recycling a desirable process (Khaliq et al. 2014; Chen et al. 2018). Therefore, their availability is paramount for their inclusion as a tool for economic sustainability (Isıldar et al. 2018). However, it is important to note that E-waste could be hazardous due to the presence of heavy metals (lead, mercury, cadmium, etc.) as well as brominated flame retardants (Kaya 2016). Therefore, proper management options should be adopted to prevent human and environmental health risks (Kaya 2016; Lu and Xu 2016). The technologies that have been successfully deployed in the recovery of metals are hydrometallurgy (use of aqueous solution in extraction of metals from the waste), pyrometallurgy (application of heat to melt appliances and recover metal) and biohydrometallurgy (bioleaching with adapted microorganisms) methods (Cui and Zhang 2008; Chauhan et al. 2018). The following section will briefly discuss these methods.

8.1.3.1.1 Pyrometallurgy for the Recovery of Metal and Energy from E-Waste

Pyrometallurgy involves the recovery of metal of interest by processing (e.g. melting, burning under high temperature) of pulverized E-waste (Cayumil et al. 2016; Ebin and Isik 2016). Most full-scale pyrometallurgical processing of WEEE scrap takes place using smelters designed for refining metals from ore or metal scrap (Townsend 2011; Chauhan et al. 2018). However, the upgrade of final metal products recovered from WEEE is a challenging task due to a mixture of pure metals and alloys after the pyrometallurgical process (Reck and Graedel 2012). Smelting of E-waste could result in the emission of environmentally persistent compounds such as dioxin from the plastic components of the waste. A large amount of slag generation, loss of precious metals and difficulty in recovery of Al, Fe and other metals are the additional problems associated with pyrometallurgical methods (Chauhan et al. 2018). A modified form – vacuum metallurgy – utilizes variation in vapour pressures existing among various metals to improve the selective recovery of desired metals (Townsend 2011). Furthermore, Zhang and Xu (2016) reported an enhanced metal extraction when pyrometallurgical technology was combined with some mild extracting reagent such as ammonia or chloride.

Recently, investigators have focused on energy recovery from E-waste to compensate the high energy demand. This is achieved through pyrolysis of plastic in the presence of suitable catalysts to produce oil with high calorific value when compared to commercial fuel (Sharuddin et al. 2016). Also, plastic components of the E-waste under the influence of catalyst have been shown to form aromatic oil (gasoline) when pyrolyzed (Muhammad et al. 2015). For instance, the plastics from equipment containing cathode ray tubes (CRTs) and also plastic waste from refrigeration equipment have been successfully converted to derivatives of aromatic hydrocarbons. Addition of the Y zeolite and zeolite ZSM-5 to the pyrolysis process resulted in a reduced concentration of styrene, but appreciable concentrations of benzene and its derivatives (toluene and ethylbenzene) were found in the product oil (Muhammad et al. 2015). Using microwave-aided pyrolysis on the plastic fraction of E-waste produced dense and viscous liquid fractions with a high concentration of useful chemicals such as xylenes and styrenes (Rosi et al. 2018).

Though pyrolysis oil could be obtained from the application of pyrolysis technology on WEEE-based plastics, the presence of the brominated flame retardants (BFRs) makes the process problematic (Wang and Xu 2014). Technology that is gasification-based and supercritical fluids methods have been suggested to achieve effective recycling with minimal impact on the environment when compared with a process such as heating at very high temperature. Other components such as glass from the cathode ray tube or liquid display glass can be reutilized sometimes to produce some precious metals such as tin and indium. Nonetheless, before any option can be used for the recycling at a commercial scale, it is very important to conduct an environmental impact assessment to ascertain the effect in the long run (Wang and Xu 2014).

8.1.3.1.2 Hydrometallurgy for Selective Metal Recovery

Compared with pyrometallurgy, hydrometallurgical methods have become desirable treatments for E-waste towards metal extraction/recovery due to reduced gas emission from the latter than the former. Other merits of hydrometallurgy include cost-effectiveness and ease of operation especially under laboratory settings (Chauhan et al. 2015). At a smaller scale, they may present a better control of the processes, thereby ensuring higher efficiency of metal recovery (Chauhan et al. 2018). In this method, alkaline or acidic leaching agents are used to wash the E-waste in order to dissolve and recover the metal of interest. This is accompanied by different forms of physical-chemical methods to finalize metal extraction (Soare et al. 2016). Chauhan et al. (2018) have shown that solvents especially halides, cyanides, thiourea and thiosulfates could be used for the leaching metals from ores.

With a view to averting the unfavourable impacts of smelting process utilized in the recovery of copper from metal powders of waste printed wiring boards rich in tin, Yang et al. (2017) have proposed hydrometallurgy as an effective technique that selectively extracts tin as well as its associated metals. For instance, alkaline pressure oxidation leaching parameters on metal conversion have been systematically investigated. The results showed that Sn, Pb, Al and small amounts of Zn in the metal powders were leached out, leaving a copper residue (Yang et al. 2017). The use of different cyanide or non-cyanide leaching techniques to recover precious and other valuable metals has been reported (Akcil et al. 2015). A novel methodology, using ammonium persulfate ($(NH_4)_2S_2O_8$), to recover gold from waste E-waste has been assayed. The findings presented by Alzate et al. (2016) revealed that $(NH_4)_2S_2O_8$ in aqueous media could be used to recover gold from E-waste. According to Sun et al. (2015), a new electrodeposition process has been proven feasible with high efficiency during copper recovery from E-waste. The leaching solutions have been analysed by ICP in order to detect the most important metals for the electrodeposition (Lekka et al. 2015). The use of hydrometallurgical techniques such as spontaneous reduction polyaniline coating of cotton fibre has been demonstrated as effective tools in gold recovery from electronic scrap (Lekka et al. 2015). Soare et al. (2016) and Popescu et al. (2018) have shown that ionic liquids can be deployed to anionically dissolve E-waste in order to recover metals such as Sn, Pb Au and Ag from multi-component alloy.

8.1.3.1.3 Biohydrometallurgy: An Eco-friendly Approach for Metal Recovery

Biohydrometallurgy has been considered as an important means of metal recovery from waste due to its cost-effectiveness and eco-friendly nature. It is also known as to conserve energy due to its ease in operation compared to other recovery techniques. Through bioleaching and oxidation reactions, different chemolithotrophic bacteria such as *Acidithiobacillus thiooxidans* and *A. ferrooxidans* have been successfully used as bioleaching agents for metal recovery from E-wastes (Chauhan et al. 2018).

An acclimatized consortium of either *Thermoplasma acidophilum* and *Sulfobacillus thermosulfidooxidans* or *S. acidophilus* and *S. thermosulfidooxidans* was used to bioleach more than 75 % of Zn^{2+}, Ni^{2+}, Cu^{2+} and Al^{3+} from E-waste pretreated with iron sulphide and elemental sulphur (Ilyas et al. 2013). Using *A. thiooxidans* (DSM 9463), bioleaching of about 99 % of neodymium, emporium and cerium and 80 % of yttrium and lanthanides from a solution of shredded dust of electronic scraps was accomplished. Also, *Pseudomonas putida* WSC361 (cyanide producer) in a further step sequestered about 45 % Au from shredded dust already bioleached with *A. thiooxidans* (Marra et al. 2018). Priya and Hai (2018) utilized exopolymeric substances produced by *A. ferrooxidans* supplemented with lemon juice to recover nickel, copper, lead and zinc from electronic-waste. Heydarian et al. (2018) demonstrated that *A. ferrooxidans* and *A. thiooxidans* were shown to be effective bioleaching tools for the recovery of cobalt, nickel and lithium from spent batteries of computers (laptops). The mediation of bioleaching of copper from E-waste by metabolites and extracellular enzymes produced by *Acinetobacter* sp. has also been reported (Jagannath et al. 2017). Using *Leptospirillum ferriphilum* as a biolixiviant, Bryan et al. (2015), dissolved metals from printed wiring boards and effectively recovered copper. In spite of various merits of bioleaching, its commercialization has not been attained due to the fact that the process is slow (time-consuming) and selective to particular groups of metals. Also, the microorganisms used in this process are often sensitive to environmental factors such as pH and temperature. Therefore, complete metal recovery using bioleaching technique has not been feasible in the majority of the cases. Thus, there is a need for investigators to develop faster and cheap bioleaching process profitable for pilot-scale operation (Chauhan et al. 2018).

8.1.3.2 Benefits, Challenges and Future of E-Waste Recycling

E-wastes are comprised of many organic heavy metals which although harmful, find great applications in some industries. In designing an efficient system for E-waste recycling, the following factors must be considered: the relevant applicable legislation, the coverage of recycling products, the capital source, the producer responsibility and the effectiveness of the execution of the recycling process (Miao et al. 2017).

There are a number of benefits accruing to the recovery of resources and recycling of E-waste. Recycling E-wastes has also been presented as a lucrative business venture. The recycling could either be formal or informal with the former being the predominant type of recycling in developed nations while the latter being the commonly practised recycling in developing countries (Ramesh Babu et al. 2007).

Major components of most electronic equipment in use today are precious and special metals. This has hence made the manufacture of various electronic products an important contributor to world demand for metals (Sthiannopkao and Wong 2013). Reuse and recycling of metal from E-waste increases metal availability for various products while reducing the dependence on mining industries for the production of new metals, with the subsequent environmental implications of mining activities (Kumar and Holuszko 2016). Recovering these metals from E-wastes paves way for urban mining and hence ensures safe disposal of these hazardous materials for environmental and public safety (Kumar and Holuszko 2016). Moreover, E-waste recovery also enables the extraction of mineral resources much needed in the electronics industry. However, in order to establish this recovery system, it is paramount to ‘consummately’ analyse the ‘environment-resource-cost’ balance (Miao et al. 2017).

The major cost constraint in the recycling of E-wastes borders on the collection and transport of the waste. In developing countries, E-wastes are collected by the informal sector (Sthiannopkao and Wong 2013). In order to abate this challenge, manufacturers of electronic products should get involved in the collection and recycling of these waste electronics as a way of incorporating social responsibility (CSR)

(Jaiswal et al. 2015). Available information indicates that there are some advantages when manufacturers of electrical/electronic appliances recycle the waste electronic products. Firstly, manufacturers can easily ascertain the flow of electronic products in the market according to the recycling amount of certain kind of products and quickly grasp the market demand information. Secondly, manufacturers are familiar with the product design process, which gives them an easy workaround when disassembling the waste electronic products and hence saves time and effort and further improves the economic benefit of the recycling process (Miao et al. 2017).

Another obstacle in the proper recovery of precious metals from E-wastes is the fact that E-wastes are frequently illegally moved from developed countries to developing nations lacking infrastructures to recycle such E-wastes and as such recover the target metals. Using low-technological methods to recover metals leads to the loss of valuable metal, thus making the recycling process a futile one (Sthiannopkao and Wong 2013).

In order to enhance the recovery of valuable materials from E-waste, the electronic product has to be disassembled. This is commonly done using crude methods especially in developing worlds. Some developed countries have developed high-tech means of recovering materials from E-wastes (Tsydenova and Bengtsson 2011). However, to improve the ease of disassembling E-wastes, electronic products can be designed so as to allow for ease of disassembly. This can go a long way in making the recovery of a variety of valuable metals from E-wastes less labour-intensive and more cost-effective. Additionally, this will make the process more sustainable by eliminating the need to use chemicals to recover metals which themselves end up as hazardous materials in the environment (Tansel 2017).

Apart from enlightening the public on the need to embrace recycling of E-waste as a green approach to its management, incentives could also be provided in order to further attract the interest of these consumers in bringing recyclable waste electronics forward. Since it has been identified that collection of these waste electronics poses a major challenge in E-waste recycling, getting the consumers to submit used electronics products to either recycling firms or to the manufacturer of such product under a pay scheme will be a boost to overcome this challenge. A transparent and organized platform where consumers bring forward E-wastes for recycling will improve the public awareness on E-wastes and thus help eliminate the rising availability of E-waste in the open environment.

The different methods that have been used to collect E-wastes hitherto include E-waste collection from households or commercial firms through governmental or non-governmental organizations, a collection of electronic scraps from solid waste garbage collectors and collection by the producers of electronic products from end-users (Jaiswal et al. 2015).

In the near future, recycling technology of E-waste would be very vital and attractive sector from the environmental and economic point of view. Recycling converts various E-waste streams to a sustainable and valuable secondary source of metals. In order to be an environmentally sustainable venture, recycling technology should manage E-waste with high efficiency and under reduced carbon footprint (Kaya 2016).

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