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E waste management: A brief review

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Abstract
Since the discovery of automated computational devices, electronics have taken over the lifestyle of whole world. They are now a very important component of day to day life and with the ever-growing demand and supply the problem of E waste have also became a huge concern over the years. E waste contain varying harmful pollutants ranging from heavy metals to organic and inorganic pollutants, which when released in the environment cause great damage. Management of these E waste have been a priority in the recent years with many policies aiming to decrease the hazardous contamination and effective reusability of end of life electronics. There are many management options available which are used to deal with this problem. All the management options have their own importance and drawbacks and, in this review, we are going to take a look on these management options along with their salient features.

Keywords: E waste, management, disposal

1. Introduction

Information and communication technology have now become a part of every aspect of life of population and became an industry with one of the largest reaches to the masses. As one the fastest growing industry in the world (Radha. G., 2002; DIT, 2003) [45, 12] the use of computers, cell phones, and other ICT equipment is expanding all over the world. Accompanying to their benefits disposal after their end-of-life has many challenges. This increased demand has resulted in an exponential increase in the waste produced by these electronics which is commonly termed as E waste. There is a considerable growth in E waste production in last decade which is contributed mainly by increase in demand and production of cheaper electronic items. It has been estimated that by year 2020, 50 billion devices will be connected to internet which is more than 6 times the population of world today (ILO, 2019) [27]. E waste is relatively small portion of solid waste produced which amount to 2.1 billion metric tons waste produced per year, but E waste defers from other solid waste like household waste, wood and paper waste in that it contains hazardous and toxic substances like heavy metals, Polychlorinated Biphenyls, along with various useful and precious metals (ILO, 2019) [27]. The hazardous material leaches into the environment and cause environmental deterioration with diseases like lead poisoning, hormonal imbalances, and cancer.

Most of the problem which is related to E waste arises due to faulty disposal and recycling methods employed for these end of life products. Most common method of E waste disposal consist of waste dumping in landfills, incineration, extended producer's responsibility, and recycling by formal and informal sectors. All these methods have their pros and cons and due to their drawbacks leaching of harmful substance in the environment occurs resulting in environmental pollution. Along with this there is a loss of many precious and rare earth minerals (e.g., gold, silver, palladium, titanium, vanadium) which are very scarce in earth.

Dumping in landfills and incineration is mostly done in developed countries because of excessive waste production and high labour cost, thus recycling becomes tedious and economically unsound. Recycling of E waste is mainly done by informal sector of underdeveloped and developing countries like Brazil, Ghana, China, India to which E waste is exported by USA, Britain, European countries. In these developing and developed nations due to lack of resources and technology, heavy environmental pollution and occupational exposure to hazardous substances occur which when combined to poverty and lack of health infrastructure leads to devastating social problems (Lines *et al.,* 2016; Barba-Gutiérrez *et al.,* 2008) [33, 4]. But along with obstacles there are opportunities like recovery of precious and rare earth metals which can provide raw materials to the market with a lower environmental footprint than mining.

Recently, the recovery of rare earth metals has attracted particular attention in view of scarce natural resources (Forti et al., 2020) [17] and it has new avenue of employment which is beneficial to the growth of developing countries. The various concerns as well as opportunities have led policymakers all over the world to create policies over E waste collection and processing and providing the necessary incentives. (Forti et al., 2020) [17]. The objective of this review was to provide comprehensive information on various E waste management methods their quality and setbacks and their impact on release of pollutants into the natural environment.

2. Current E waste scenario
In the 12th meeting of 'Basel Convention' which is short for "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal" technical guidelines were adopted in which E waste is defined as "Electrical or electronic equipment that is waste, including all components, subassemblies and consumables that are part of the equipment at the time the equipment becomes waste" (ILO, 2019) [27]. UNEP also defined 'E waste' as "any electrically powered appliance that fails to satisfy the current owner for its originally intended purpose" (Chaudhary, 2018) [7]. These definitions of E waste include all the end to term and disposed, large and small electrical equipments and make it easier to classify as well as collect data regarding production and collection.

The production of E waste has increased in an incredible pace in previous year producing 53.6 metric tonnes. This produced E waste is 9.2 Mt more than the amount produced in year 2014 and if this continues as it is now than by 2030 projected production of E waste will be 74.4 Mt. It Means production has doubled in only 16 years and considering the hazardous effects and loss of rare metals it is a substantial. Asia generated the highest quantity of E waste in 2019 amounting to 24.9 Mt, America (13.1 Mt) comes at second followed by Europe (12 Mt), while Africa and Oceania generated only 2.9 Mt and 0.7 Mt. Even if Asia is at the top considering the population and area, per capita generation comes only 5.6 kgs and for Africa it is only 2.5 kgs but Europe comes with 16.2 kg per capita at top. World average generation is 7.3 kg per capita. (Forti et al., 2020) [17].

Out of all the E waste generated; formally collected and recycled in 2019, was 9.3 Mt which is only 17.4% of total waste generated. Comparing it with the figures of 2014 it grew with 1.8 Mt with an annual growth of almost 0.4 Mt but considering the growth rate of waste production which is almost 2 Mt annually the recycling is not on par with production growth. The highest recycling rate is observed in Europe with 42.5% followed by Asia with 11.7% and lowest rate of recycling is observed in Africa at 0.9%. The fate of the rest 82.6% is still uncertain and its environmental impact varies according to region. Around 8% of E waste find its way in dust bins and thus prevent them from recycling and thus ends in dumping grounds and landfills. Transboundary E waste movements can be estimated in around 7-20% and this results to the most pollution generated because of informal recycling in developing and underdeveloped nations (Forti et al., 2020) [17].

3. Impact of E waste
The hazardous effects of E waste can be credited to its inherently hazardous nature of constituents coupled with improper disposal methods. From toxic release in the environment and habitat to human health effects the impact range of E waste is vast. Ranging from heavy metals in E waste to various other constituents like phthalates present in PVCs to Polychlorinated biphenyls (PCBs) released from capacitors, printing inks and hydraulic fluids (Otake et al., 2001; Hedman et al., 2005; Wikstrom and Marklund, 2001) [39, 21, 60] these all constituents are released during dismantling process and cause various health hazards in workers like damage to kidneys and peripheral nervous tissues due to lead poisoning to chronic damage to brain as well as bioaccumulation of mercury in fishes. Burning PVCs release dioxins that cause reproductive and health problems along with these there are various persistent organic pollutants also associated with E waste (Sankhla et al., 2016) [46].

Studies in china revealed that crude methods of E waste dismantling with management options is one of the leading cause of adverse environmental effect like contaminated soil, water and human health effect when coupled with increasing amount E waste. (Zhao et al., 2010; Wang et al., 2011; Frazzoli et al., 2010; Tsydenova and Bengtsson, 2011) [64, 59, 55]. Most of E waste leads to landfills where leachates with heavy metal concentration was found to be toxic and exceeding environmental limits particularly in aquatic environment and organism. (Dagan et al., 2007) [11]. Burning is another toxin releasing method of E waste handling.

Antibiotic sensitivity is another problem related to heavy metals present in E waste. Heavy metals present in E waste promote antibiotic resistance by acting as a co-selecting agent. Co-resistance and cross-resistance are two methods found to be the cause of antibiotic resistance (Baker-Austin et al., 2006; Knapp et al., 2017) [2, 31]. Research have found that most resistance is found in zinc and cadmium and most common organism found to be affected by this resistance is P. Aeruginosa and E. Coli. World Health Organization, have stipulated that antibiotic resistant bacteria will emerge as leading cause of death by 2050. (O'Neill, 2016) [36].

E waste handlers are directly affected by these substances and most of the time they are not aware of the risk involved. A study conducted in Nigeria reported that 88% of workers cannot name a single hazardous substance present in E waste and only 12% have little knowledge of occupational safety (Ohajinwa et al., 2017) [38]. The residents living near E waste recycling sites are also much more exposed to these hazards specially the vulnerable population group like infants and old people (Sankhla et al., 2016) [46].

4. E waste management options
Management of E waste is considered to be on the most challenging problems in electronic industry and has been an issue of environmental and policy makers concerns ever since it has been acknowledged. Management option generally have two main pathways one is to either change the production process and material used as well as careful planning to decrease the pollutants and their release in the environment or disposal either through traditional means like landfills or through recycling. Each of these methods have their own pros and cons and should be considered when making policy.

4.1 Life cycle assessment (LCA)
Life cycle assessment is a powerful instrument used to access the environmental impact of a product which helps to design an eco-friendly design and rearrange or make products much more viable for environment and also appeal to the customers. This tool has been used by many researchers to identify the

environment impact of products like home computers (Kim *et al.,* 2001) [30], toys (Muñoz *et al.,* 2009) [35], washing machines (Park *et al.,* 2006) [40] and printers (Pollock and Coulon, 1996) [41]. It also systematically defines many categories which have environment impact like ozone layer effect, acidification, carcinogenesis, climate change impact, eutrophication, land use, and ecotoxicity, to further improve the product's environmental performance (Belboom *et al.,* 2011; Duan *et al.,* 2009; Environment Canada, 2000; Emmenegger *et al.,* 2006; Hischier and Baudin, 2010; Schischke and Spielmann, 2001; Socolof *et al.,* 2005; Bakri *et al.,* 2008; Yanagitani and Kawahara, 2000) [5, 13, 15, 14, 23, 49, 52, 3, 63]. LCA has been used extensively for E waste impact analysis by various researchers. Hischier *et al.* (2005) [24] studied the Swiss resuse and recycling system's environmental impact and found recycling system to advantageous over incineration. Likewise Lu *et al.* (2006) [34] in Taiwan studied the notebook computer disposal alternative and found that reuse and second-hand sales to be much more environmental friendly than recycling. The studies conducted in various countries using LCA showed that recycling is best method of disposal than incineration and landfilling (Apisitpuvakul *et al.,* 2008; Choi *et al.,* 2006; Hischier *et al.,* 2005; Kim *et al.,* 2004; Scharnhorst *et al.,* 2005; Wäger *et al.,* 2011)[1, 10, 24, 29, 47, 57]. But it is not always the same as recycling method also have impact is environment (Barba-Gutiérrez *et al.,* 2008; Lu *et al.,* 2006) [4, 33].

4.2 Multi-criteria analysis (MCA)
MCA is a tool of decision making, developed for solving multicriteria problems which are complex and include quantitative and qualitative aspects of problem along with strategic decisions. (Garfì *et al.,* 2009) [19]. It includes various criteria and analyses many scenarios to find the most profitable and suitable production and distribution method. MCA method have been applied to E waste and environmental problems previously. Hula *et al.* (2003) [25] used this decision-making method to know the trade-offs between economic profit and environmental impact of coffee makers which are at end of life stage. Queiruga *et al.* (2008) [44] even used MCA to select the location best for E waste recycling plants in Spain. MCA is more widely used for solid waste management rather than E waste management (Cheng *et al.,* 2003; Herva and Roca, 2013; Vego *et al.,* 2008) [9, 22, 56] and hazardous waste management (Hatami-Marbini *et al.,* 2013; Sharifi *et al.,* 2009) [20, 50]. Nevertheless, it has been recommended for social response to E waste management (Williams, 2005) [61] and has been a very useful when used in conjugation with other tools.

4.3 Material flow analysis (MFA)
It is another type of decision-making tool which considers the flow of E waste and data accumulated through various sources in a software-based simulation modelling (Ibrahim *et al.,* 2013) [26]. MFA is used to study the material flow route of E waste going into the recycling plants or sites, or areas of disposal and stocks. It links the pathways, sources and destinations of material and is a decision support tool for waste and environment management (Brunner and Rechberger, 2004) [6]. For E waste it has been used various times. Shinkuma and Nguyen Thi Minh (2009) [51] investigated the E waste flow in Asia using MFA. This tool can be used to develop a useful management strategy for E waste which includes a flow consideration of E waste and

assessment of economic, environmental, social, and environmental values.

4.4 Extended producer's responsibility (EPR)
Extended producer responsibility is a policy aimed to give manufacturers the responsibility of end of life collection of waste electronics and electricals as well as improvement in design and processes to decrease the environmental impact of product. It is based on principle that whoever pollutes should pay for its removal. This principle first came in an international forum by OECD council in 1972 (Schempp, 2011) [48] and was adopted as principle 16 at UN Rio declaration in 1992 on environmental development which mentioned that any fabricator that makes the device should take the responsibility to collect at the end of life stage from assembly. EPR is validation to this principle (Forslind, 2005) [16]. EPR was realised by a Swedish bill passed in early 1975 which was related to environment protection and conservation of resources (Wang *et al.,* 2017) [58]. Later the EPR concept was brought forward by Prof. Thomas on Sweden in 1990 (Thomas, 2000) [53]. It was defined extensively in 2001 by the OECD as EPR is "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (OECD, 2001) [37]. OECD compliance countries have made regulations regarding EPR along with many non-OECD countries like India and Thailand. It is national scale measure and one of the most promising one when used with other tools and policies are being made continuously revolving around it. Financial aids have been provided by government for this but in the countries where financial policy designing is rigid EPR has become a costly arrangement.

4.5 Disposal
Since the harmful effects of E waste have been realised in the recent years only, the disposal methods employed for traditional waste have been used largely for E waste also, resulting in considerable pollution and damage to the environment due to largely differing composition of E waste than household and municipal solid waste. After the knowledge exposure of presence of precious and rare minerals in E waste and means of recycling them in known to world, recycling E waste have started in large scale which is done by formal or informal means in which informal recycling makes up larger portion. Thus, disposal of end of life electronic waste generally follows two routes, one is to dispose in conventional municipal landfills or indirectly as discard during recycling process. Both the methods have their own drawbacks.

4.5.1 Landfill
A landfill can be considered as oldest form of waste disposal method where waste is buried in land pits. Most of the E waste ends up in landfills. These landfills are generally considered as the most hazardous form of waste disposal if no prior treatment is done to the waste before dumping. Modern landfills are capable of isolating the harmful substances but still poses threat. E waste is dumped in these landfills. The harmful substances present in landfills percolates and get mixed in soil and percolates through bed rock and get mixed in ground water around the landfills (Wong *et al.,* 2007) [62]. This process is termed as leaching and substances is known as leachates. Leachates can contain very high concentration of harmful organic, inorganic and heavy metals whose

concentration depends on characteristics of waste and the stage of waste decomposition (Qasim and Chiang, 1994) [43]. Research on leachability of various heavy metals like copper zinc iron and lead has been conducted in various types of electronic equipments (Kasassi *et al.,* 2008) [28] It has been found that lead concentration in devices such as mobile phones and laptops exceed 5mg/L and have high leachability (Townsend *et al.,* 2004) [54]. Studies have also reported that incineration of E waste prior to dumping drastically decrease the level of certain harmful components which are destroyed during combustion (Li *et al.,* 2007) [32]. This method is being employed in Japan to decrease pollution (Li *et al.,* 2007) [32].

4.5.2 Recycling
Recycling of E waste denotes converting whole or parts of E waste into products which are usable. Vast quantities of E waste are produced each year and thus large quantities of reusable material are also produced which when recovered lower the cost as well as environment footprint but if the recycling method is not refined then this method itself can cause great harm to the environment. The method employed in recycling depends on type of material, size, and available resources. Recycling in developed countries are a costly affair due to high labour cost and strict regulations. In developing and underdeveloped countries recycling is mostly informal affair, done by untrained workers by crude methods resulting in high environment impact. This results in contamination of soil air and water in the adjoining areas and expose people. The major pollutants released in the environment are heavy metals like nickel, lead, chromium, cadmium, arsenic, and mercury, organic pollutants like brominated flame retardants (BFRs), PAHs, PBDEs etc. (Puckett and smith., 2002; Chen *et al.,* 2009) [42, 8].

5. Conclusion
It is clear that if the matter of E waste is not taken seriously in the near future by the policymakers than it can lead to disastrous future where concern is not only environment pollution but also lack of resources due to use of many rare earth minerals in electronics which will decrease the growth of technological advancement. The management of this problem does not only concern the policy makers but also to the consumers, manufacturers and society as a whole. The responsibility of manufacturers should be to make the product recyclable and reusable as much as possible and consumers should not only be made aware of the dangers regarding faulty disposal method but also given easier assessable options to manage the end of life electronics. Policy makers should also emphasize to train the workers and providing infrastructure for more efficient recycling by bringing formal and informal recycling sectors together. Using the management options in conjugation with other, problem can be dealt with awareness and sense of responsibility.

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