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Electronic Waste (E-Waste): Sources, Proliferation, Effects & Management in Developing Nations

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Abstract. High-performance electrical devices have resulted from the amazing growth and advancement in high technology in the commercial, aviation, military, car, scientific industries, general household, and consumer goods, and so on. As a result, a wide variety of electrical devices have entered the market. This electrical and electronic equipment, on the other hand, contribute to the expanding global waste stream, particularly in developing economies. Plastics and polymer components in these devices contribute to electronic waste, along with a slew of other components that are thought to be toxic to humans and the environment directly or indirectly. Electronic waste is a blend of utilized or undesirable electronic items that have surpassed their period of usability. It is one of the quickest developing waste in developing economies and records for nearly 5% of all city strong waste each year. The Information and Communication Technology (ICT) segment is a noteworthy wellspring of e-waste whose hardware contains various electrical parts; forming the biggest percentage of e-waste all over the globe. This is because of the development of the ICT division which has improved the utilization of electronic equipment exponentially coupled with frequent upgrades of these devices; thereby causing a quicker out-of-date quality ICT hardware. This act of upgrades is compelling users and shoppers to dispose of their older versions of the different gadgets, which thusly amass gigantic e-waste to the strong waste stream. This expansion of e-waste presents wellbeing perils for our territory and the biological environment because of their dangerous nature and in this manner contaminate our landfills by exuding poisons that saturate submerged supplies. In this paper, we review the system for the legitimate gathering of e-waste, safe strategies for recycling and reusing of material, appropriate methods for transfer of e-waste.
Keywords:E-Waste; Information and Communication Technology (ICT); Life Cycle Assessment (LCA); Material Flow Analysis (MFA); Multi-Criteria Analysis (MCA); Extended Producer Responsibility (EPR).

I. INTRODUCTION

Electronic waste (E-waste) is defined as unwanted, unused, or outmoded electronic products that are nearing the end of their useful life (Sovacool, 2019). E-waste is said to be the world's fastest-growing hazardous solid waste category (Guo et al., 2020; Kang et al., 2020). All types of outmoded electronic components contribute to electronic waste, such as video recorders being replaced by DVD players and DVD players being replaced by Blu-ray scanners. The Industrial Revolution and the advent of information technology have transformed human existence in recent years, resulting in the spread of electronic waste. Many electronic devices, as a result of this technological deed, outlive their usefulness after a few years of operation. While this has helped humanity, mismanagement has created new kinds of pollution and pollution-related issues (Ramachandra and Saira, 2004). An estimated 44million tons of E-waste is generated globally every year in 2016, with Southeast Asian countries and China generating a very large portion (Kang et al., 2019; Salam and Varma, 2019; Osibanjo,2016). Local disposal strategies employed by using scavengers have brought about outcomes unfavorable to the surroundings, the economy, ecology, and lives of people (Dagan et al., 2007). As more developing countries join the global Information Society, the amount of electronic garbage produced is steadily increasing. In addition, due to lax laws, electronic gadgets are rarely destroyed, putting the environment and people in the area at risk. China, Germany, Japan, Indonesia, the United States, Brazil, Russia, France, India, and Italy are among the countries that generate the most electronic waste (e-waste) (Salam and Varma, 2019). Although the natural world has not yet turned into a multibillion-dollar business worldwide, there are many losses in developing countries.

The last century's technological advancements have posed a new challenge to waste management. Plastics and plastic additives, as well as some very poisonous components such as bromine, precious and dangerous metals (such as copper and gold, arsenic, mercury, and lead), physiologically active compounds, chlorinated substances, acids, and toxic gases, are all found in personal computers. These compounds include hazardous components that damage the environment and human health. The strategies of treating e-waste in developing countries stimulate the pollution of air, soil, water, and sediment, with consequent bioaccumulation in land and aquatic animals (Dagan R, Dubey B, Bitton G, 2007; Osibanjo, O., Nnorom, I.C., Adie, G.U., Ogundiran, M.B., Adeyi, 2016). Therefore, proper disposal or recycling of electronic waste is required. Today, computers are the most used tools for all types of activities, in schools, homes, offices, and the manufacturing industry. Toxic computer components E consist of heavy metals such as brominates flame retardants for printed circuits, cadmium and lead in printed circuit boards, lead oxide and barium in cathode ray tubes, cadmium batteries and PVC in PVC buildings for cable computers copper and mercury in transformers, flat screens and printed circuit boards in capacitors, old transformers, etc. Basel Action Network (BAN) estimates that 500 million computers worldwide contain 2.87 billion pounds of plastic, 716.7 million kilograms of lead, and 286,700 kilograms of mercury. The 14-inch screen uses an average tube with 2.5 to 4 kg of lead. Lead can penetrate the water level of the landfill and contaminate it. When the pipe is squeezed and burned, toxic fumes are released into the air (Kellyn, 2008; Ramachandra and Saira, 2004).

1.1 Sources of E-Waste

Electronic waste is obtained from various sources of electronic products such as IT and telecommunications equipment, household appliances, consumer appliances, industrial tools, lighting equipment, toys, recreational and sports equipment, medical equipment (except for all implantable radiotherapy equipment) used and disposed of monitoring and control instruments, automatic dividers, etc. The usual situations for these IT and telecommunications sources include used cell phones, chargers, cameras, CDs, remote controls, headsets, CD players, televisions, radios, photocopiers, clocks, CRT monitor, LCD/Plasma, welders, computer motherboard, keyboard, typewriter, etc. Electronics from industrial and consumer electronics include ovens, grills, refrigerators, fax machines, sewing machines, and the like. Washing machines, fans, air conditioners, grinders, irons, heaters, military, aviation, automobile, and laboratory electronics (Mmereki et al., 2016).

1.2 E-Waste Composition

Each electronic device is made up of hundreds of different, toxic, and valuable materials, such as iron, aluminum, plastic, and glass account for more than 80% of e-waste, while the amount of valuable and toxic substances is small but still of great importance. According to (Mmereki et al., 2016), the composition of electronic waste is dependent on the type of electronic device, model, manufacturer, date of production, and age of the plants. Computer waste and telecommunications systems contain more precious metals than household appliances. For example, cell phones contain more than 40 elements, base metals like copper (Cu) and tin (Sn), specialty metals like lithium (Li), cobalt (Co), indium (In), and antimony (Sb), as well as precious metals like silver (Ag), gold (Au), and palladium (Pd). Special treatment of electronic waste should be considered to prevent valuable materials and rare items from being consumed. Extraction of gold and palladium from electronic waste is more efficient than ore. The fraction including iron, copper, aluminium, gold, and other metals in e-waste is over 60%, while pollutants comprise 2.70% (Widmer et al., 2005).

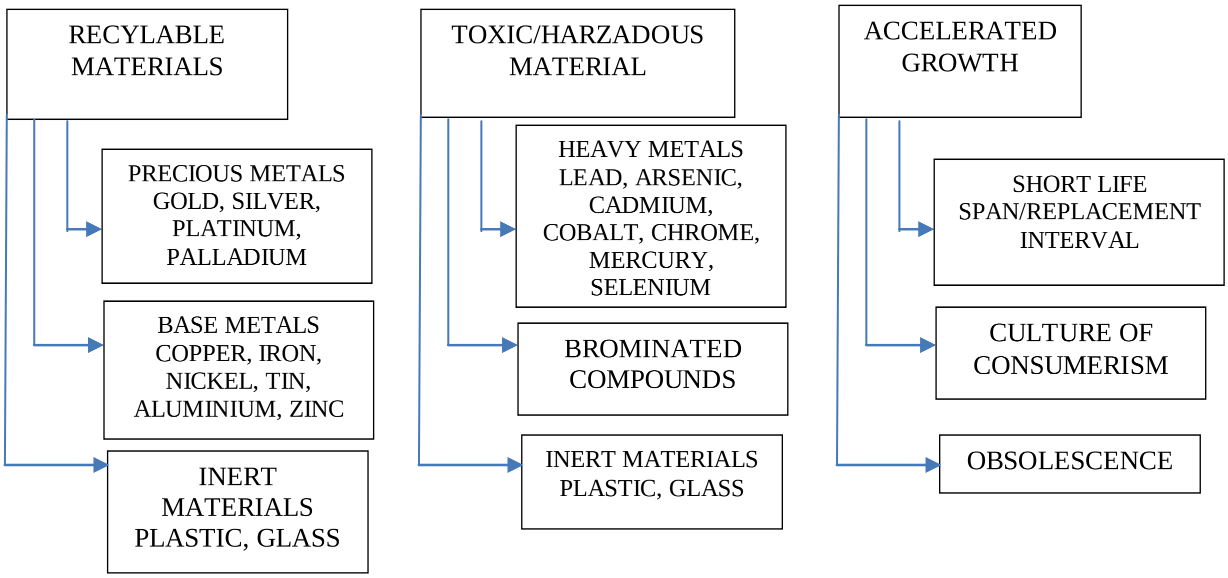

Figure 1 Characteristic composition of e-waste (Cherukuri, 2018)

Also, a typical Bleriot-treated printed circuit board in an electronic device contains about 50 grams of tin-lead solder per square meter of Printed Circuit Board (PBC). End-of-life (EOL) cathode ray tubes (CRT) for computer screens and televisions contain high-quality constituents such as zinc, copper, barium, lead, cadmium, and other infrequent earth metals. For example, objects such as lead glass can prevent the generation of x-rays when projecting CRT images. The average index for CTR monitors is 1.6 to 3.2 kg. For example, the United States and other industrial countries of the European Union and Japan have barred the disposal of cathode ray tubes at landfills due to their toxicity. A major obstacle in the design and development of e-waste management strategies is the numerous component changes caused by technological advances, especially in electronic components. In this context, the recovery and management of e-waste must be in line with changes in the composition of e-waste. The composition of e-waste is influenced by various factors, including economic conditions, re-use of market accessibility and recycling of industrial infrastructure, waste classification systems, and law enforcement. Figure 2 shows the various materials used for waste electrical and electronic equipment (Mmereki, et al., 2016).

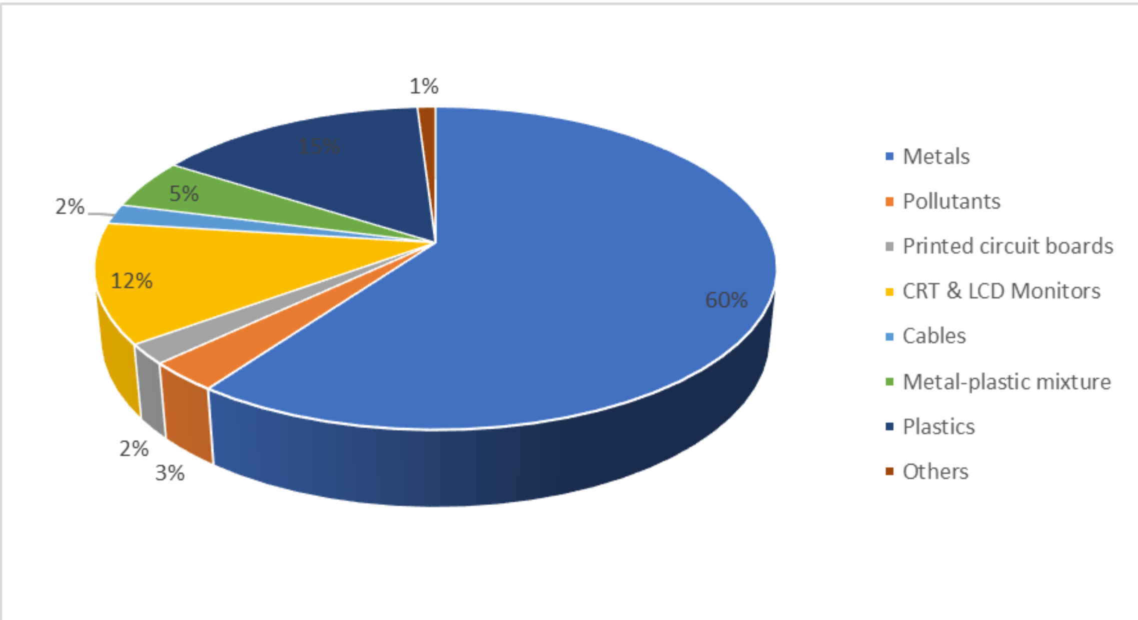

Figure 2 The composition of a WEEE. Source: Adapted from (Dagan et al., 2007)

1.3 Classification of E-waste

The components of electronic waste are diverse and fall into the 'dangerous' and 'non-dangerous categories. It is generally made of plastics, non-ferrous metals, printed circuits, rubber, glass, concrete, ceramics, wood, plywood, and other objects. Iron and steel represent approximately 50% waste, followed by plastic (21%), non-ferrous metals (13%), and other components. Non-ferrous metals consist of metals like aluminium, copper, and precious metals such as platinum, silver, palladium, gold, etc. (Ohajinwa and Bodegom, 2018).

Electric waste is naturally hazardous as it exceeds levels of lead, mercury, arsenic, cadmium, selenium, chronic equilibrium, and flammable substances. It contains more than 1000 different substances, most of which are poisonous and, after use, can seriously contaminate the environment (Great Lakes Electronics Corporation,2020). Old computers are one of the biggest risks to the environment and health of electronic waste. Most devices are based on polychlorinated biphenyls, which contain many harmful substances: lead, cadmium, mercury, anatomy, adhesion, arsenic, and BFR (Lucier and Gareau, 2019). However, Original Equipment Manufacturers (OEMs) reduce these dangerous relationships by confiscating devices under the Restriction of Certain Hazardous Substances (RoHS) guidelines.

Table 1 Components, Electrical and Electronic Equipment Containing Hazardous Compounds.

S/No.	Components	Compounds of concern	Applications
1	Printed Circuit Boards (PCBs)	Pb, Sb in solder, Cd and Be in contacts and switches Hg in switches and relays Ga, as in LEDs BFR in batteries	Found in PCs and most electronics.
2	Toner cartridges	Toner, including carbon black	Laser printers, copying machines, and faxes,
3	Plastics and Polymers	PVC, Teflon, Cd, Pb, and phthalates as polymers BFRs, Cd, Pb, Org, Sn, and phthalates as additives	Wire insulation, plastic housing, circuit boards, etc.
4	Liquid Crystal Displays (LCDs)	Liquid crystals in screens	Laptops, mobile phones, television sets
5	Batteries	Ni and Cd in Ni-Cd batteries, Pb in lead-acid batteries, Hg in Hg batteries	Portable electronic devices.
6	Cathode Ray Tubes (CRTs)	Pb and Sb in CRT glass, metals such as Cd in the glass, Phosphor Ba in electron gun getter	Oscilloscopes, PC monitors, and old television sets
7	Various Hg containing components	Hg	Thermostats, sensors, relays, switches, gas discharge lamps, medical equipment, and telecom equipment
8	PCB-containing capacitors	PCB	In various electronic circuits
9	Refrigerating circuits	Freon	Refrigerators, freezers, air-conditioners

Source: Swedish Environmental Protection Agency Report 6417 (Vats and Singh,2014; Grigore,2017)

1.3.1 Plastics in Waste Electrical and Electronic Equipment (WEEE)

Plastics in waste electrical and electronic equipment (WEEE) have received interest in recent years due to their increased volume, high content of hazardous substances, and poor waste treatment. Estimated projections are that WEEE generation will reach 52.2 million tonnes per annum by 2021(Stenvall,2013). Recyclable polymeric/plastic materials do constitute components of electrical and electronic equipment that span domestic appliances, mobile phones to advanced engineering structures. It has been discovered through composition studies that there are more than 15 dissimilar types of plastics (polymer resins) (Martinho et al., 2012) selected and used for a wide variety of electric/electronic applications(Grigore, 2017; Grigorescu et al., 2019). The discarded electrical and electronic equipment are referred to as Waste Electrical and Electronic Equipment (WEEE) or E-Waste as expressed by the European Union (EU). WEEE contain toxins which when deposited in landfills present grave environmental concerns. Regardless, they also contain reusable materials like metal, gold, glass, plastics, and platinum. The presence of plastics in e-waste poses more concern due to different compositions as plastic blends and hazardous additives present in the plastics (e.g., halogenated flame retardants in styrene-based plastics).

1.3.2 Plastic WEEE characterization

WEEE contains 20-64 wt% plastics (Dimitrakakis et al., 2009; Stenvall, 2013). Small plastic e-wastes studied in Dresden, Germany contained over one-third of ABS plastics followed closely by PP at 28.83%.In another study by COMBIDENT project conducted on 634 plastic samples, also had ABS waste as the most used plastic in electronics at 30%,HIPS at 25%,the least of which was PBT(2%) (Freegard et al., 2006).

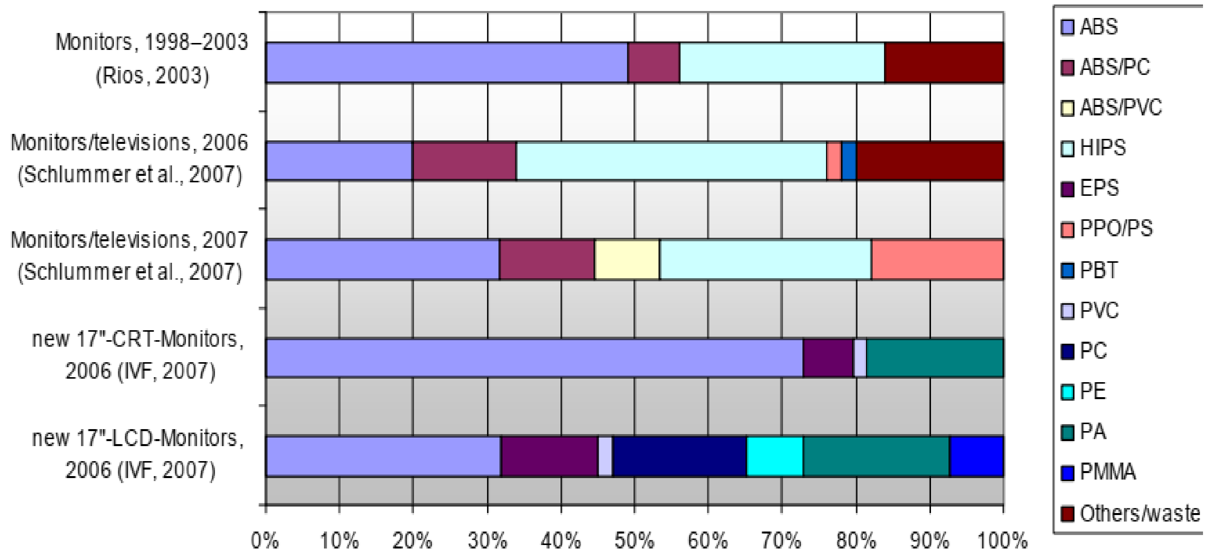

Figure 3 Plastic composition of PC monitors from different sources (Wäger et al., 2009)

II. PROBLEMS OF E-WASTE

A look at a computer or a mobile phone from its outer shell does not appear dangerous to the user but inside components contain harmful products such as lead, mercury, and copper, which affects the environment, humans, and animals (Babayemi et al., 2017). The computer waste deposited at landfills contributes to contaminating the groundwater and causes global pollution leading to sterilization. The burning of electronic waste contributes to environmental pollution. The improper disposal of waste is a danger to the environment (Obaje, 2013). The long-term exposure of the following types of chemicals containing arsenic, beryllium, chromium, and cadmium causes a harmful effect to the skin, heart, lungs, and kidneys. Therefore, damage to these important organs can be the cause of the life expectancy of our people (Ramachandra and Saira,2004; Sylvanus,2014). Electronics offer a variety of problems to the environment and human health as described below:

Table 2 Effect of E-Waste on the Environment

E-Waste component	Process Used	Potential Environmental Hazard
Cathode beam tubes found in television sets, PC monitors, ATMs, camcorders	Breaking and expulsion of burden, at the point of dumping	Barium, Lead, and other overwhelming metals drain into the groundwater and the arrival of harmful phosphor
Plastics from keyboards, printers, and monitors	Destroying, crushing, grinding, and low temperature softening for reprocessing to be reused	The outflow of brominates dioxins, overwhelming metals and hydrocarbons
PC Cables	Stripping to evacuate copper	Polycyclic aromatic hydrocarbons (PAHs) discharged into the air,

		water, and soil
Chips and components plated with gold	Synthetic stripping, utilizing nitric and hydraulic corrosive and consuming of chips	PAHs, overwhelming metals, brominates fire retardants released straightforwardly into streams, acidifying fish and verdure. Tin and lead sullying of surfaces and groundwater. Air outflow of brominates dioxins, substantial metals, and PAHs

On the off chance that these electronic things in table 3 are disposed of with other family trash, the toxics represent a danger to both wellbeing and imperative parts of the biological system. The unsafe substances, their events, and their effects on human wellbeing and condition (Ara, 2013) are fused in Table 4.

Major sectors that generate e-wastes are (i) individuals and small businesses(ii) large businesses, institutions, and governments; and (iii) OEMs.There are several reasons electrical electronic equipment (EEE) reach their end-of-life: (i) technical obsolescence (ii) features obsolescence (iii) economic obsolescence (Ogungbuyi et al., 2012)

Table 3 Toxic components in e-waste, their occurrence, and impact

Sources of e-waste component	**Toxic metals**	**Limit, ppm**	**Disease caused by exposure to the above permissible limit**
Ceramic capacitors, switches, batteries	Ag[a]	5.0	Excessive amount causing blue pigments on the body damages brain, lung, liver, kidney
Monitors, keyboard, cabling, and plastic computer housing	PVC[b]	0.03	Hazardous and toxic air contaminants, the release of HCI causes respiratory problems
Batteries, luminous substances	Zn[b]	250.0	Nausea, vomiting, pain, cramps, and diarrhea
Transistor, LED lead-acid batteries, solder CRT, PCBs, fluorescent tubes	Pb[c]	5.0	Damages brain, nervous system, kidney, and reproductive system, causes acute and chronic effects on human health
Electron tube, lubricant, fluorescent lamp, CRT gun	Ba[b]	<100	Causes brain swelling, muscle weakness, damage to the heart
Printed Circuit Boards (PCB)	CN[b]	<0.5	Cyanide poisoning,>2.5 may lead to coma and death
Mobile, telephone, batteries	Li[a]	<10d	Diarrhea, vomiting, drowsiness, muscular weakness
Gallium arsenide is used in light-emitting	As[b]	0.5	Chronic effect and causes skin disease and lung cancer and impaired nerve signaling
Power supply boxes, motherboard	Be[b]	0.75	Causes lung cancer, berylliosis, skin disease, carcinogens
Plastic computer hosing, cabling, hard discs as a colourant 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 the brain, kidney and foetuses

Batteries, semi-conductor, CRT, PCB	Ni[a]	20.0	Causes allergic reaction, bronchitis,reduces lung functons, lung cancer
Transistor, led lead-acid battery, solder,CRT, PCB, Florescent Tubes	Pb[b]	5.0	Damages brain, nervous system, kidney and reproductive system
Cooling units and insulation foam	CFCs[b]	1.0	Impacts on the ozone layer which can lead to greater incidence of skin cancer
Fax machine, photoelectric cells	Se[b]	1.0	High concentration causes selonsis
PCBs, Casing, PVC cables	Br[b]	0.1	Thyroid gland damage, hormonal issues, DNA damage, skin disease, hearing loss
CTR glass, plastic computer housing, and a solder alloy	SB[b]	<0.5	Carcinogen, causing stomach pain, vomiting, diarrhea, and stomach ulcer
CTR, Batteries	Sr[c]	1.5	Somatic as well as the genetic changes due to this cancer in bone, nose, lung, and skin
Transformer, capacitor, condensers	PCBs[b]	5.0	PCB causes cancer in animals and can lead to liver damage in humans
PCBs, battery, CRT, semi-conductors, infrared detectors, printer ink, toners	Cd[b]	1.0	Pose a risk of irreversible impacts on human health particularly the kidney

Source from (Pathak et al., 2017), "[a] Critical; [b] Hazardous and toxic; [c] Radioactive waste; [d] limit in serum/blood. From the above Table, we can understand that there are many dangerous effects on human health from e-waste".

III. METHODOLOGIES IN E-WASTE MANAGEMENT

There is currently extensive research into the disposal of electronic waste to reduce challenges at both local and global levels. Below are some efforts to achieve strategies for the disposal and implementation of electronic waste:

3.1 Basel Convention

The principal targets of the Basel Convention adopted in 1989 are to control and diminish the danger of transboundary developments of perilous and different waste, comprising the anticipation and minimization of their creation, the correct ecological administration of such squanders, and the advancement, circulation, and use thereof (Sylvanus et al., 2014). A draft of the vital designs for the execution of the Basel Convention was proposed. The vital arranging undertaking will consider existing local plans, projects or methodologies, choices of the Conference of the Parties and their auxiliaries, continuous venture exercises, and the procedure of ecological administration and maintainable improvement. The design needs to exploit all facets of society: training, data, interaction, methodological devices, the ability for grants, transfer of experts, knowledge, and health, cleaner, and more proven technologies and processes to help ensure compliance with the Basel Declaration. It also requires the effective involvement and coordination of key stakeholders, which is a common but essential responsibility for accomplishing the goals of the Basel Declaration (Ramachandra and Saira, 2004).

Below are several strategies for communicating and supporting the detailed implementation of site activity (Galli,2017).

- Involve experts in the development of communication tools to raise awareness of the Basel Declaration, improve environmental management, ratify, and implement the Basel Agreement, changes, and procedures.
- Involve and encourage a team of stakeholders to assist the Secretariat in raising funds for policy and project preparation, and to make full use of expertise in NGOs and joint projects.
- Motivate selected partners of different participants to create benefits at short notice.
- Disseminating information and disseminating knowledge in print media, Internet, and other electronic means, particularly through the Basel Convention Regional Centers (BCRC).

- Carry out a regular evaluation of the activities related to the established pointers;
- to cooperate with current organizations and programs to promote clean technologies and capacity building for better management of environmental risks, methods, economic instruments, or strategies and the management of other waste.

The Basel Convention has postponed the transboundary shipment of perilous waste. India and different nations have ratified and implemented the resolution of the convention. In any case, the United States (USA) isn't engaged with the boycott and is at present in charge of the transfer of dangerous waste, for example, electronic waste in Asian nations (Ogungbuyi et al., 2012). Industrialized nations like the US must uphold exacting laws in their nation to avoid this grievous demonstration. In the European Union, the yearly number of electronic pieces will twofold in the following twelve years, as the European Parliament has as of late passed laws expecting makers to restore their electronic items to buyers. This is called expanded maker obligation and most poisonous substances in electronic items additionally require an auspicious disposal schedule (Sovacool,2019).

3.2 Tools for Disposal of Electronic Waste

In waste management, numerous techniques were developed and utilized such as Life Cycle Assessment, MFA, MCA, and EPR. The disposal of electronic waste in industrialized countries has taken another step with the publication of the WEEE Directive, which aims to eliminate this waste and improve the quality of the environment. The study incorporates the partition of recyclable segments and the reusing of uncommon and valuable metals (Biganzoli et al., 2015). This segment gives a review of the picked methodology and features for future advancement. This section gives an overview of the chosen approach and highlights future development

3.2.1 Life Cycle Assessment (LCA)

This method is a logical system that is ordinarily, centred on asset utilization and effects on human wellbeing and nature-related with assembling of explicit items. The primary bit of leeway of LCA is that it eases issue-moving thinking about the full scope of applicable effects. Lifecycle appraisal (LCA) for waste administration frameworks is planned by indistinguishable standards from LCA for items and procedures (Streicher-Porte,2007; Rousis,2008). A naturally amicable plan is a superior elective item and, at the same time, can appeal to consumers. LCA is widely used for the management of e-waste. The significant strides in the LCA of waste administration frameworks are:

- Scope definition (characterizing framework limits and parameters);
- Stock examination (distinguishing sources of info and yields of all procedures in the lifecycle);
- Sway appraisal (setting evaluation criteria; measuring the natural effect);
- Information understanding (dissecting and looking at all effects and performing affectability examination).

With the four above back-to-back stages, LCA is as yet an iterative procedure; i.e., the aftereffects of information elucidation can help to tweak the previous periods of the investigation (Grigore,2017). One of the key phases of LCA is swaying evaluation since it creates numerical information that can legitimately influence ends from this appraisal. The primary four stages in effect appraisal are:

- Setting evaluation criteria;
- Defining or picking scoring framework (model);
- Normalization of effects;
- Weighing of effects.

In light of distributed writing, LCA is a well-known device as of now being utilized for e-waste the executives including the structure and item improvement and ecological basic leadership in numerous nations including United Kingdom Columbia, Thailand, Switzerland, Japan, India, Taiwan, Korea, and Germany (Shah, 2015).

3.2.2 Material Flow Analysis (MFA)

MFA is one of the important devices that is utilized by advanced nations to deal with the perplexing waste flow (Kiddee et al., 2013). As indicated by (Streicher-Porte et al., 2007), "MFA is a term utilized in investigating stream of issue matter (compounds, chemical elements, materials or commodities), which upheld by material adjusting that speak to the material protection law". Before the entry into force of the Basel Treaty, much of the waste was exported from advanced nations for reuse in developing nations, including South Africa, India, and China. MFA is a device used to think about the progression of materials (e-waste) to locales or destinations for reusing and waste, in reality. Connections sources, courses, and middle and last destinations

(Galli et al., 2017).

MFA is an environmental policy choice-making and waste management tool. MFA is to a great extent utilized in the nations that have enormous reusing plants, for example, in Nigeria, India, and China assess the location of e-generation (Işıldar,2018). The studies carried out by (Shah,2015) were to assess the amounts of electronic waste and they found that the generation of electronic waste in Nigeria, India, Chile, and China would increase. For example, according to the MFA, e-waste was projected to grow two-fold from 2005 to 2010 as well as 70% in China by 2020, while they were four to five times larger during 2010-2019 in Chile. In (Streicher-Porte et al., 2007), the MFA and financial worth evaluation were utilized as a device for breaking down the Au and Cu framework coming about because of PC reusing in India. A study by (Streicher-Porte et al., 2007) shows that the link between MFAs and economic valuation can be a useful tool when data are limited and in the event of rapid economic growth (Kiddee et al., 2013).

3.2.3 Multi-Criteria Analysis (MCA)

The MCA is a policy selection device that has been developed to implement planned policy options and to address difficult Multi-Criteria issues, including quantitative/qualitative parts of the problem (Shah, 2015). Although MCA is often not used for electronic waste management, it is mainly used for solid waste and unsafe waste management (Biganzoli,2015). MCA is regulated for the common response to e-waste management and is, therefore, a valuable device in combination with the various tools used to manage and control e-waste (Ogungbuyi,2012). MCA is used for basic leadership when it comes to natural and monetary benefits, the best area of e-waste reuse facilities, and is the best alternative for transferring electrical waste (Pandey, 2016). Even though MCA is a useful tool for basic ecological leadership, it is not widely used to manage and control e-waste. The EPR is a device that is completely focused on the strategy and tasked the creator to reclaim items and handle the process and this depends on the polluter paying the head (Shah, 2015).

3.2.4 Extended Producer Responsibility (EPR)

EPR introduced in the EU in 1996 is an e-waste management strategy that mandates the manufacturer to take responsibility for retrieving all used products back from the environment for appropriate disposal and possibly recycling them based on the polluter-pays principle (PPP) (Kiddee and Naidu,2013; Rousis,2008; Zhang and Xu,2019). Developed countries like Japan, Canada, Switzerland, the USA (United State of America), EU (European Union) were the first to establish EPR Programmes in e-waste control and management. As reported in (Kiddee et al., 2013), "OECD (Organization for Economic Cooperation and Development) bolstered an ecologically amicable program and distributed a direction manual for government". EPR is at present accessible in various developed and developing countries such as Japan, Germany, Thailand, India, United Kingdom, Switzerland, Netherlands, and some parts of the United States and Canada. Nevertheless, adherence to EPR arrangement shifts among nations with many developing nations is with views that it is difficult to contact the end-user to actualize the EPR policy to deal with overseeing e-wastes. D nations, for instance, Switzerland and Japan have advanced with the use of EPR and this is acknowledged via enterprises related through electronic merchandise (Pongracz et al., 2008).

IV. E-WASTE RECYCLING

The administration of sustainable recycling of waste electrical electronic equipment (WEEE) requires the advancement of state-of-the-art collection, and treatment strategies as well as novel metal recovery technologies, due to its peculiar material composition (Işıldar et al., 2018). E-waste consists of various plastics, metals, and other organic materials hence the complexities in recycling. Currently, most environmentally friendly and economically viable treatment techniques include, hydrometallurgy, pyrometallurgical technology, mild extraction technology, electrochemical technology (Li et al., 2019), and vacuum metallurgical technology, focus on recycling valuable resources (Zhang and Xu, 2019), little attention is given to constituents of e-waste that are not recyclable.

The technical process of e-waste recycling: (Biganzoli,2015; Chen,2019)

→ Collection
→ Pre-processing
▪ Separation of integrated material content and directing different material fractions to the appropriate recycling process.
▪ Disassembly – extraction of toxic or useful parts (e.g., batteries)
▪ Upgrading – utilizing mechanical procedures to prepare material for refining
→ End processing
▪ Recycling through refining – certain materials are returned as secondary materials sources for further use

- Incineration
- Disposal of materials that cannot be recycled and with no reselling value

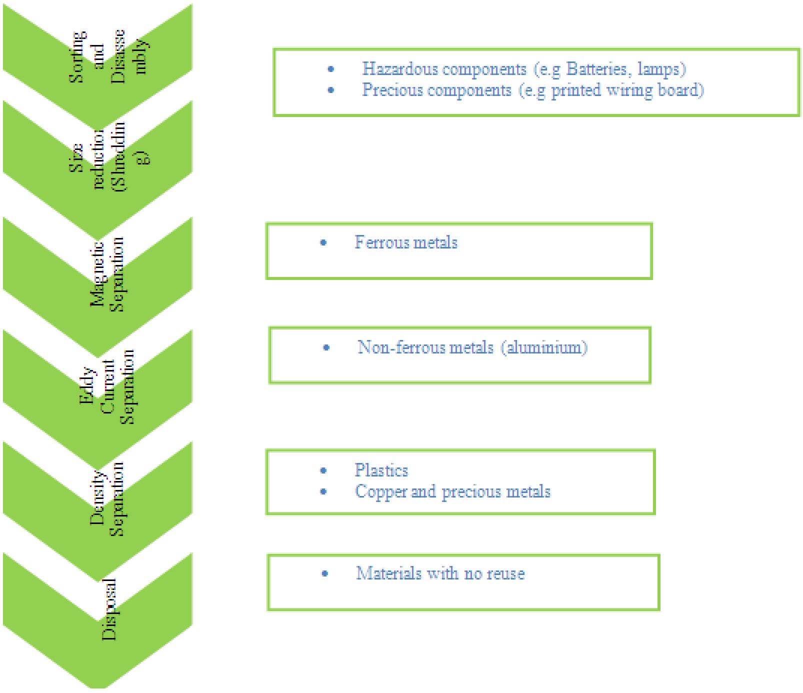

Figure 4 Flow process of e-waste preprocessing (Tanskanen, 2013)

4.1 Recycling of Plastic (WEEE)

WEEE recycling is still fraught with different challenges. One of such challenges is the insufficient(Sahajwalla & Gaikwad, 2018) and high cost of separation technology required to extract the individual polymers from a blend(Stenvall, 2013) and insufficient profit from the venture (Zhao et al., 2018), and avoidance of excessive degradation of the polymer(Stenvall, 2013)

It has been seemingly determined that solid e-waste has a global rapid growth mostly because of the rate (2–3 years or less), at which electronic/electrical equipment becomes obsolete in functionality and trend(Costa et al., 2017), giving rise to a generation of e-waste at 3 – 5% annually(Chen et al., 2019). Nevertheless, these plastic materials are suitable for recycling through the methods of Mechanical (primary and secondary), gasification, pyrolysis, micro-factories, and solvent extraction(Hamad et al., 2013; Sahajwalla and Gaikwad, 2018). However, sorting out distinct polymeric/plastic from assemblies of waste electrical and electronic components in the course of their recovery is a tedious affair especially because it would require meticulous dismantling and separation before other recycling stages (Grigorescu et al., 2019).

The principle of plastic recycling using the solvent extraction method, also classified as secondary mechanical recycling, involves the expulsion of impurities, and plastic additives (Zhao et al., 2018), dissolution, and recrystallization. In essence, the polymer blend is dissolved in the solvent(s) and the individual plastic is recovered by cooling, centrifugation, reprecipitation, or complete drying in a hot gas stream(Garcı et al., 2013). The solvent extraction method offers many advantages;(i) insoluble contaminants are removed by filtration leaving the polymer clean for further reprocessing (ii) This process allows to separate plastics from other types of waste and polymers non-soluble depending on their chemical nature. (iii) Polymer degradation is non-existent unless heat is used for dissolving the plastic wastes (iv) energy efficient, nontoxic and nondestructive. Recovered plastic have comparable quality as their virgin counterparts (Vane and Rodriguez, 1992). The extraction process utilizing mixed solvents to recover polycarbonate (PC) can produce over 95% recovery, with purity as high as virgin PC at the same time using less energy and less toxic. The dissolution process is influenced by the solvent concentration, polymer and solvent type and polymer molecular weight (Garcı et al., 2013)

Table 4 Solvents for plastic reprecipitation

Plastic	Strong solvent	Weak solvent
PS	Toluene	n-hexane
PE	Xylene	Propanol
	Xylene	n-hexane
PP	Xylene	n-hexane
PET	N-methyl-2-pyrrolidene (NMP)	-
ABS	ACE	-
PVC	Dichloromethane (DCM)	Methanol

Another approach to recycling plastic WEEE is extrusion melt-processing. Recovered plastics possess properties comparable to their virgin material. The stiffness and yield stress of the recycled polymer blend is higher, while the elongation at break is lower than the values for the virgin blend (Stenvall, 2013).

Modern initiatives for the recycling of polymer WEEE tilts towards the use of micro recycling (microfactory technology) (Sahajwalla and Hossain, 2020), also applied in the recycling of metals. Micro recycling realizes the transformation of materials as an effect of temperature and time (Osibanjo et al.,2016). The idea is to utilize properties present in plastic e-wastes such as chain structure, thermomechanical properties, and carbon content. In the end, the transformed plastic e-waste products are new and of high value.

Notable developments of microfactory technology for recycling plastic WEEE include (i) the conversion of waste toner powder to about 98% pure iron (ii) transformation to 3D printing filaments (iii) converting waste CDs into graphitic carbon(Rajarao et al., 2014) (iv) the use of computer casing as a source of carbon for the manufacture of silicon carbide (Vorrath, 2017)

V. DISCUSSION

The disposal of obsolete electronic equipment requires an implementation framework, which involves the creation of eco-planned devices to properly assemble e-waste, apply safe procedures to recover and reuse material and utilize sensible frameworks to dispose of e-waste. Besides, the law should be established to prohibit the transfer of used electronic devices to developing countries and carry out a campaign Programme for both end-user and manufacturers on the impact of e-waste pollution. This is the most commonly used method today in industrialized countries, but the developing countries have not yet put in place an appropriate mechanism and blueprint for the implementation of these e-waste management techniques. Youth education in these countries can be an instrument for disposing of electronic waste. There are many facilities for the disposal of electronic waste, but some countries have a good reputation and focus on LCA, MFA, MCA, and EP (Kiddee et al., 2013). Table 6 presents the significance of the e-waste management devices: LCA, MFA, MCA, and EPR.

Table 5 Significance of E-Waste Management Tools

E-Waste Tools	Significance
Life-Circle Assessment or Analysis (LCA)	• Approximate the impacts of resources utilization. Behaviours evaluation of eco-structured and item advancement • Makes better choices concerning e-waste transfer • Assigns the effects of the analyzed item or procedure of ecological intrigue • To evaluate financial and ecological perspectives recognized with the arrangement of electronic gadgets.
Material Flow Analysis (MFA)	• To explore e-waste progression • To appraise the creation of e-waste • Expended in ecological policy choice
Multiple Criteria Analysis (MCA)	• Expended in ecological policy choice
Extended Producer Responsibility (*EPR)*	• To solve e-waste pollution on a national scale • To enforce makers dependent on polluter-pays ahead

Overall, the tools listed in Table 6 are useful for the disposal of electronic waste. When the disposal of electronic waste is required, each environmental management tool has a specific category of information, some of which is covered. The results show that LCA, MFA, and MCA have overlay conservational decision-making mechanisms, each device has a unique separator identifier that distinguishes them from EPR, used at the national level, especially concerning national policy shown in figure 6, as well as the PPP. For example, a blend of MFA or ACM, LCA, and EPR will possibly emerge as the best approach to promote the disposal of electronic waste, regardless of the type of difficulty. The EPR is perhaps the best suitable solution to reduce the production of electronic waste by all parties since the responsibility for electronic waste created under the Basel Convention has been transferred to the manufacturers (Pandey,2016).

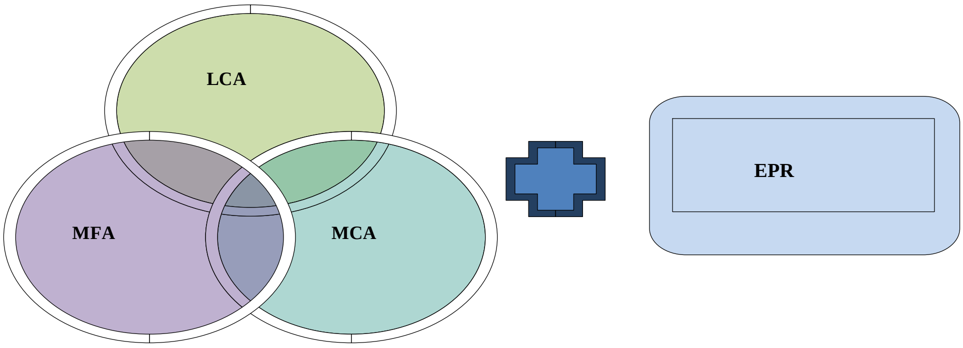

Figure 5 Integrated Methods **-** LCA, MFA, MCA, and EPR of e-waste Management

VI. CONCLUSION

Electronic waste is a grave challenge to both local as well as global economies. The subject of electronic waste first appeared in industrialized countries and is now spreading to other countries of the 3rd world. With the rapid evolution of consumer technology, the number of e-waste has increased rapidly and technological innovations have led to the rapid proliferation of diverse devices and gadgets, generating a large amount of electronic waste. Some e-waste contains toxic constituents that can pollute and endanger the ecosystem and therefore require a proper and guided disposal scheme (Alessandra et al., 2017). Numerous case studies in electronic waste recycling facilities have confirmed that toxic chemicals such as heavy metals and persistent organic pollutants pollute and continue to pollute the environment. This leads to a high accumulation of pollutants in the ecosystem, through either landfilling or incineration, leading to the leaching of chemicals and release of toxic gases (Sunil et al., 2018) that are harmful to human health. Laboratory simulation studies in landfills and laboratories show that toxic substances are released by e-waste. There are concerted efforts by various governments across the globe on e-waste management geared towards reducing the level of e-waste to mitigate against the potential effect on human health and the environment. The quest for efficient and effective e-waste management led to the implementation of tools like MCA, LCA, EPR, and MFA to solve most electronic waste problems. Each of these tools may be imperfect but can be added side by side to solve the problem. It is pertinent for every nation to establish EPR Policy tools to help curb the increasing challenge of electronic waste. E-waste management summarily involves the integration of four interactive tools, which consists of enacting a law to prohibit the transfer of obsolete electronic waste, proper collection of waste, development of environmental protection devices, and recycling of materials safely by the appropriate technical treatment of electronic waste. There should be a proper enlightenment program for both manufacturers and end-users on the inherent danger of the transfer of used electronic equipment to developing countries. The end-user should be willing to accept and adhere to the established strategies, which have advantages, irrespective of the number of strategies implemented.

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