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ELECTRONIC WASTE MANAGEMENT: A REVIEW

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Abstract— The electronic industry is the world's largest and fastest growing manufacturing industry. It has become leverage to the socio - economic and technological growth of a developing society. The consequence of its consumer oriented growth combined with rapid product obsolescence and technological advances are a new environmental challenge - the growing menace of "Electronics Waste" or "e waste" that consists of obsolete electronic devices. The current practices of e-waste management in India suffers a number of disadvantages like inadequate legislation , difficulty in inventorisation, health hazards due to informal recycling, poor awareness and reluctance on part of the corporate to address the critical issues. The impacts are intense when toxic materials enter the waste stream with no special precautions, creates adverse effects on the environment and human health and when economically valuable materials are dumped resources are wasted or unhealthy conditions are developed during the informal recycling. Current article gathers the current scenario of E waste generation, data on components and hazardous substances of e-waste that are creating environmental pollution and human exposure to these chemicals, resulting adverse effects due to recycling, incineration and landfill disposal of e-waste.

Keywords— *e-waste, environmental issues, health impacts and management.*

I. INTRODUCTION

Discarded electronic waste is the fastest growing stream of waste in industrialized countries (Toxics links, 2004). Electronics are changing the lives of people everywhere – starting from the way we do business, bring up children, keeping touch with others or personal entertainments. Not surprising, the electronics industry is the fastest growing manufacturing industry. Consumers are drawn to the latest cellular phones, laptops, air conditioners and consumer electronics. The obsolescence of these products leads to a unique mindset where consumers preferred to replace the products rather repair and reuse. The rapid obsolescence is also due to the rapid evolving technology but on the other hand it is clear that the throw away principle yields monetary benefits to corporate. In the wake of this 21st century revolution, this

throw away principle is sure to damage the quality of our lives and the generations to come. The problem of electronic waste, or e-waste, requires global action (Balde et.al, 2015).

II. WHAT IS E WASTE?

Electronic waste, e-waste, e-scrap, or waste electrical and electronic equipment (WEEE) describes discarded electrical or electronic devices. "Electronic waste" may also be defined as discarded computers, office electronic equipment, entertainment device electronics, mobile phones, television sets and refrigerators which are made of sophisticated blends of plastics, metals, and other materials. This definition includes used electronics which are destined for reuse, resale, salvage, recycling and disposal. The European Union (EU) defines this new waste stream as Waste Electrical and Electronic Equipment. Since there is no definition of the WEEE in the environmental regulations in India, it is simply called 'E-waste'. According to Gui et al (2003), "WEEE is diverse and complex in terms of materials and components as well as the manufacturing process. Characterization of this waste stream is of paramount importance for developing a cost effective and environmental friendly recycling system". E-waste is categorized by the Government of India under the broad class of hazardous waste. Within e-waste, there are several categories such as large and small household appliances, electrical and electronic toys and sporting equipment, tools, computers and related equipment etc. which contains metallic and non metallic elements, alloys and compounds such as Copper, Aluminium, Gold, Silver, Palladium, Platinum, Nickel, Tin, Lead, Iron, Sulphur, Phosphorous, Arsenic etc. The fraction includes over 60% of metals, while plastics account for about 30% and the hazardous pollutants comprise only about 2.70%.

A. Global generation of e-waste

The global quantity of e-waste generated in 2014 was around 41.8 Mt. Driven by the national laws for e-waste management, around 6.5 Mt was reported as formally treated

through take-back systems. In 28 European Union states, around 0.7 Mt of e-waste was thrown into the waste bins. The amount of e-waste that is thrown in bins is unknown for other regions. However there is a gap between e-waste generated, officially collected and those in waste bins. Most importantly, official data for the transboundary movement of e-waste are unknown. Most of the e-waste (i.e 16 Mt) was generated in Asia. This amount of e-waste is 3.7 kg/inhabitant. Europe has generated 15.6 kg/inh, the highest per inhabitant e-waste quantity globally. The lowest quantity of e-waste was generated in Oceania and was 0.6 Mt. The whole African continent generated 1.9 Mt of e-waste which is 1.7 kg/inh. The Americas generated 11.7 Mt in total out of which 7.9 Mt from North America, 1.1 Mt from Central and 2.7 Mt from South America which represents 12.2 kg/inh. The global e-waste quantity in 2014 comprises 1.0 Mt lamps, 3.0 Mt of small IT, 6.3 Mt of screens and monitors, 7.0 Mt of cooling and freezing equipment, 11.8 Mt of large equipment and 12.8 Mt of small equipment. The amount of e-waste is expected to grow to 49.8 Mt in 2018, with an annual growth rate of 5% (balde et.al, 2015).

B. Indian Scenario

The electronics industry has emerged as the fastest growing segment of Indian industry both in terms of production and exports. The share of software services in electronics and IT sector has gone up from 38.7 per cent in 1998-99 to 61.8 percent in 2003-04. A review of the industry statistics show that in 1990-91, hardware accounted for nearly 50% of total IT revenues while software's share was 22%. The scenario changed by 1994-95, with hardware share falling to 38% and software's share rising to 41%. This shift in the IT industry began with liberalization, and the opening up of Indian markets together with which there was a change in India's import policies vis-à-vis hardware leading to substitution of domestically produced hardware by imports. Since the early 1990s, the software industry has been growing at a compound annual growth rate of over 46%. The e-waste inventory based on the obsolescence rate and installed base in India for the year 2005 has been estimated to be 146180.00 tonnes. This has exceeded 8,00,000 tonnes in 2012 (CII).

India ranks third position in highest e-waste generation among Asian countries. The country has generated 1.7 Mt in absolute quantities for the year 2014 (balde et.al, 2015). Sixty-five cities generate more than 60% of the total e-waste generated in India. Ten states generate 70% of the total e-waste. Maharashtra ranks first followed by Tamil Nadu, Andhra Pradesh, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh and Punjab in the list of e-waste generating states. Among top ten cities generating e-waste, Mumbai ranks first followed by Delhi, Bangalore, Chennai, Kolkata, Ahmedabad, Hyderabad, Pune, Surat and Nagpur. There are two small e-waste dismantling facilities are functioning in Chennai and Bangalore. There is no large scale organized e-waste recycling facility in India and the entire recycling exists in unorganized sector. There is a lack of authentic and comprehensive data on e-waste availability for domestic generation and the various State Pollution Control Boards have initiated the exercise to collect data on e-waste generation.

III. E-WASTE ISSUES

Based on the outcome of the studies carried out and the consensus arrived at the National Workshop on electronic waste management held in March 2004 and June 2005 organised by CPCB and Ministry of Environment & Forests, an assessment was made of the existing practice in the e-waste management. The following issues were identified from the assessment.

A. Increasing amount of E- Waste

Product obsolescence is becoming more rapid since the speed of innovation and the dynamism of product manufacturing / marketing has resulted in a short life span (less than two years) for many computer products. Short product life span coupled with exponential increase at an average 15% per year will result in doubling of the volume of e-waste over the next five to six years.

B. Toxic components

E-waste are known to contain certain toxic constituents in their components such as lead, cadmium, mercury, polychlorinated bi-phenyls (PCBs), etched chemicals, brominated flame retardants etc., which are required to be handled safely. The recycling practices were found inconsistent in informal sectors leading to uncontrolled release of toxic materials into the environment as a result of improper handling of such materials.

C. Lack of environmentally sound recycling infrastructure

It has been established that e-waste, in the absence of proper disposal, find their way to scrap dealers, which are further pushed into dismantler's, supply chain. Existing environmentally sound recycling infrastructure in place is not equipped to handle the increasing amounts of e-waste. The major dismantling operations are occurring in unorganized/informal sector in hazardous manner. The potential of increased e-waste generation and lack of adequate recycling facilities have attracted the attention of a number of recyclers globally, expressing interest to start recycling facility in India.

D. Impacts on environment

E-waste constitutes heavy metals, persistent organic pollutants, flame retardants and other potentially hazardous substances. These pollutants can cause risks to the environment if not managed properly. During recycling and material recovery three main groups of substances are released in to the environment which needs high priority attention as they are highly hazardous in nature. The first group is the original constituents of equipment such as lead and mercury, second group such as cyanide, added during some recovery processes and third group which are formed during recycling processes such as dioxins and furans. If improperly managed, such substances may pose significant human and environmental health risks (Joseph, 2007). The following types of emissions or outputs show the presence of toxic substances in e-waste handling and management. leachates from dumping activities pollute the soil and water resources, coarse and fine particulate matter from dismantling, bottom and fly ashes from burning activities, fumes from mercury amalgamate, desoldering and

other burning activities, wastewater from dismantling and shredding facilities and effluents from cyanide leaching and other leaching activities (Lundgren, 2012).

Improper breaking or burning of printed circuit boards (PCBs) and switches may lead to the release of mercury, cadmium and beryllium which are highly toxic to human health (Handout 10, 2012). Another dangerous process is the recycling of components containing hazardous compounds such as halogenated chlorides and bromides used as flame-retardants in plastic, which form persistent dioxins and furans on combustion at low temperatures. A study on burning printed wiring boards in India showed alarming concentrations of dioxins in the surroundings of open burning places reaching 30 times the Swiss guidance level. About 70% of the heavy metals especially mercury and cadmium, in landfills come from electronic waste. Consumer electronics is the root cause for the presence of about 40% of the lead in landfills. These toxins can cause brain damage, allergic reactions and cancer (WHO, 2010). The highly dispersed recycling units across India, results in problems such as emissions of dioxins and heavy metals like lead, cadmium, mercury in air, indiscriminate dumping of spent fluids and chemicals thus contaminating soils, groundwater contamination through leachate, land filling of non-recyclables and release of BFR (Sharma et al, 2012).

E. Occupational health impacts of e-waste

There is little regulation in the informal sector to safeguard the health of those who handle e-waste. Workers are poorly protected in an environment where e-waste from PC monitors, PCBs, CDs, motherboards, cables, toner cartridges are burned in the open and release lead and mercury toxins into the air. Many of these workers complain of eye irritation, breathing problems and constant headaches (Li et al, 2011). Some critical occupational health issues are inadequate working space, poor lighting and ventilation, straining the eyes and breathing polluted air, sitting cramped on the ground for long hours, inhaling toxic fumes, exposure of body parts to fire, acid and other chemicals and unavailability of clean drinking water and toilets. The best example is the town of Guiyu in south-east China. Since 1995, the traditionally rice-growing community of Guiyu has turned into an intensive informal e-waste recycling centre, probably the largest in the world. Researchers observed many health effects in relation to the rudimentary recycling techniques (Lundgren, 2012).

F. Regulatory regime for e-waste

In India, there are specific environmental laws or Guidelines for e-waste exists. E-waste (Management and Handling) Rule, 2011 has come into force from May 2012. The other international initiatives are explained below to manage the flow of e-waste.

1) *The Hazardous Wastes (Management and Handling) Rules, 2003*: The Hazardous Waste (Management and Handling) Rule, 2003, defines "hazardous waste" as any waste which by reason of any of its physical, chemical, reactive,

toxic, flammable, explosive or corrosive characteristics causes danger or likely to cause danger to health or environment, whether alone or when on contact with other wastes or substances, and shall include Waste substances that are generated in the 36 processes indicated in column 2 of Schedule I and consist of wholly or partly of the waste substances referred to in column 3 of same schedule. Waste substances that consist wholly or partly of substances indicated in five risks class (A,B,C,D,E) mentioned in Schedule 2, unless the concentration of substances is less than the limit indicated in the same Schedule. Waste substances that are indicated in Lists A and B of Schedule 3 (Part A) applicable only in cases of import and export of hazardous wastes in accordance with rules 12, 13 and 14 if they possess any of the hazardous characteristics listed in Part B of schedule 3.

2) *Basel Convention*: Basel Convention covers all discarded/disposed materials that possess hazardous characteristics as well as all wastes considered hazardous on a national basis. Annex VIII, refers to E-waste, which is considered hazardous under Art. 1, par. 1(a) of the Convention: A1180 Waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries included on list A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g., cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III. Annex IX, contains the mirror entry, B1110 Electrical and Electronic assemblies given below.

- Electronic assemblies consisting only of metals or alloys
- Waste electrical and electronic assemblies or scrap (including printed circuit boards) not containing components such as accumulators and other batteries included on List A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or not contaminated with Annex 1.

IV. MANAGEMENT OF E-WASTE

In this context, it is pertinent to assess the e-waste recycling scenario in India, where recycling of e-waste to recover items of economic value is carried out. The assessment of e-waste recycling sector in India indicates that e-waste trade starts from formal dismantling sector and moves to informal recycling sector. E-waste movement from formal to informal sector is driven by trade and can be tracked by trade value chain. This e-waste trade value chain can be mapped based on material flow from formal sector to informal sector. This chain was identified considering bottom-up approach with three levels of e-waste generation hierarchy. The three levels of e-waste generation hierarchy give rise to three types of stakeholders involved in e-waste trade as described below.

- 1st Level – Preliminary e-waste Generators.
- 2nd Level – Secondary e-waste Generators.

- 3rd Level – Tertiary e-waste Generators.

The following are the steps involved in an e-waste management facility. In a formal sector the e-waste is segregated into different streams depending on their material composition and recycling potential. After which the hazardous nature is checked to understand its reuse or disposal options.

A. composition and recycle potential

The composition of e-waste and its recyclable potential is specific for each appliance. In order to handle this complexity, the parts or materials found in e-waste may be divided broadly into six categories as follows:

- Iron and steel, used for casings and frames
- Non-ferrous metals, especially copper used in cables, and aluminum
- Glass used for screens, windows
- Plastic used as casing, in cables and for circuit boards
- Electronic components
- Others (rubber, wood, ceramic etc.).

B. Methodologies

The approach and methodology to determine the hazardousness has been described in following steps. This approach follows the basis used by “Department for Environment, Food and Natural Affairs”, Government of United Kingdom to classify E-waste. However, it has been customized as per Indian situation.

- Step 1: Identification of E-waste category
- Step 2: Identification of E-waste composition or determine it
- Step 3: Identification of possible hazardous content
- Step 4: Identifying whether the E-waste component is hazardous or the entire E-waste item is hazardous.

C. Recycling, Reuse and Recovery

The composition of e-waste consists of diverse items like ferrous and non ferrous metals, glass, plastic, electronic components and other items and it is also revealed that e-waste consists of hazardous elements. Therefore, the major approach to treat e-waste is to reduce the concentration of these hazardous chemicals and elements through recycle and recovery. In the process of recycling or recovery, certain e-waste fractions act as secondary raw material for recovery of valuable items. The recycle and recovery includes the following unit operations.

1) *Dismantling*: Removal of parts contains dangerous substances (CFCs, Hg switches, PCB); removal of easily accessible parts containing valuable substances (cable containing copper, steel, iron, precious metal containing parts, e.g. contacts).

2) *Segregation of ferrous metal, non-ferrous metal and plastic*: This separation is normally done in a shredder process.

3) *Refurbishment and reuse*: Refurbishment and reuse of e-waste has potential for those used electrical and electronic

equipments which can be easily refurbished to put to its original use.

4) *Recycling/recovery of valuable materials*: Ferrous metals in electrical are furnaces, non-ferrous metals in smelting plants, precious metals in separating works.

5) *Treatment/disposal of dangerous materials and waste*: Shredder light fraction is disposed of in landfill sites or sometimes incinerated (expensive), CFCs are treated thermally, PCB is incinerated or disposed of in underground storages, Hg is often recycled or disposed of in underground landfill sites. The value of recovery from the elements would be much higher if appropriate technologies are used.

D. TREATMENT & DISPOSAL

The presence of hazardous elements in e-waste offers the potential of increasing the intensity of their discharge in environment due to land filling and incineration. The potential treatment disposal options based on the composition are

1) *Land filling*: The degradation processes of e-waste in landfills are very complicated and run over a wide time span. At present it is not possible to quantify environmental impacts from E-waste in landfills for the following reasons: 1) Landfills contain mixtures of various waste streams; 2) Emission of pollutants from landfills can be delayed for many years; 3) According to climatic conditions and technologies applied in landfills (e.g. leachate collection and treatment, impermeable bottom layers, gas collection), data on the concentration of substances in leachate and landfill gas from municipal waste landfill sites differs with a factor 2-3. One of the studies on landfills reports that the environmental risks from land filling of e-waste cannot be neglected because the conditions in a landfill site are different from a native soil, particularly concerning the leaching behavior of metals. In addition, it is known that cadmium and mercury are emitted in diffuse form or via the landfill gas combustion plant. Although the risks cannot be quantified and traced back to e-waste, land filling does not appear to be an environmentally sound treatment method for substances, which are volatile and not biologically degradable (Cd, Hg, CFC), persistent (PCB) or with unknown behaviour in a landfill site (brominated flame retardants). As a consequence of the complex material mixture in e-waste, it is not possible to exclude environmental (long-term) risks even in secured land filling.

2) *Incineration*: Advantage of incineration of e-waste is the reduction of waste volume and the utilization of the energy content of combustible materials. Some plants remove iron from the slag for recycling. By incineration some environmentally hazardous organic substances are converted into less hazardous compounds. Disadvantage of incineration are the emissions to air from substances escaping flue gas cleaning and the large amount of residues from gas cleaning and combustion. There is no available research study or comparable data, which indicates the impact of e-waste emissions into the overall performance of municipal waste

incineration plants. Waste incineration plants contribute significantly to the annual emissions of cadmium and mercury. In addition, heavy metals not emitted into the atmosphere are transferred to slag and exhaust gas residues and can reenter the environment on disposal. Therefore, e-waste incineration will increase these emissions, so reduction measures like removal of heavy metals are necessary.

V. E WASTE MANAGEMENT STRATEGIES

A. Policy level initiatives

The Policy shall address all issues ranging from production to final disposal, including environmentally sound technology for the recycling of electronic waste. Regulations to control both legal and illegal exports and imports of e-wastes must be clear in the policy. Loop holes in the prevailing legal frame work also to be addressed to prevent or reduce the transboundary movement of e-waste from developed to developing countries. The disposal of e-wastes in municipal landfills must be prohibited in the regulations strictly. Owners and generators of e-wastes should be encouraged to properly recycle their wastes by providing financial incentives. Manufactures of products must be made financially, physically and legally responsible for their products. Policy must emphasize management of restricted substances through awareness among producers and manufactures in the new product development. Environmental hazard labeling of products to create awareness among the general public must also to be covered in the policy. A complete national level inventory, covering all the cities and all the sectors must be initiated. A public-private participatory forum in E-waste management must be developed.

B. Extended producer responsibility

Extended producer responsibility (EPR) is an environmental policy approach in which a producer's responsibility for a product is extended to the post consumer stage of the product's life cycle, including its final disposal (Joseph,2007). All vendors of electronic devices shall provide take-back and management services for their products at the end of life of those products. The old electronic product should then be sent for recycling or re-use, either in a separate recycling division at the manufacturing unit or in a common facility. Collection systems are to be established through collection centers to ensure proper collection and transportation directly to the recycling unit. Recyclers that are having authorization for handling, processing, refurbishment, and recycling meeting environmentally sound management guidelines should only be given permission.

C. Training and awareness programmes

The e-waste management in the future depends not only on the effectiveness of policy level initiatives from the government, effectiveness in recycling services, but also on the attitude of buyers. Lack of awareness among the residents to segregate e-waste from municipal waste is increasing the magnitude of e-waste problem in India. Community

participation must be initiated in order to understand the key role of manufactures and bulk consumers in e-waste management. Awareness raising programmes and activities on issues related to the environmentally sound management (ESM), health and safety aspects of e-wastes may be conducted in order to encourage better management practices among different target groups. Consumers to be educated to buy only necessary products that utilize emerging technologies such as use of lead-free, halogen-free products to be identified through eco-labeling. ESM of e-wastes can be well organized with a help of technical guidelines which emphasis on better collection, recycling and disposal options.

VI. CONCLUSION

The current article summarizes the scenario of e-waste generation in India and in other countries. definition, material composition, current disposal methods, hazardous nature of e-waste is also presented to understand the hazardous nature of e-waste in the form of heavy metals and halogenated compounds. Improper handling and management of these waste during recycling and other end-of-life treatment options seems to have potential risks to both human health and the environment. The lack of public awareness regarding the disposal of electronic goods and inadequacy of policies to handle the issues related to E-waste enhance the problem in India. There is no large scale organized E-waste recycling facility in India and most of the recycling exists in unorganized sector. Moreover, the management practices are often poorly designed and have a lot of health and environmental issues. There exists an urgent need for a detailed assessment of the current and future scenario including quantification, characterization, existing disposal practices, environmental impacts and occupational health hazards. e-waste collection, transportation, treatment, storage, recovery and disposal, need to be established, at national and/or regional levels for the environmentally sound management of e-wastes.

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