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Assessing the Environmental Impacts Associated Withthe Life Cycle of Electronic Equipment

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Abstract: *Electronics is increasingly becoming a part of many aspects of life. This has led to a fast growing demand for electronic. The production of electronics requires various materials, energy, man-force and other resources. The various stages of production have their share of impact on the environment. Discarding these electronics poses another, rapidly increasing, danger on the environment. This is the issue of e-waste or electronic waste. A lot is being done to reduce the problems being caused by the electronic industry, but with optimization even more environment-friendly and economical solutions are possible. Environmental planning involves production in a sustainable manner with consideration given to the natural environment, social, political and economic factors. This paper broadly talks about the impacts, of the current practices of the electronics industry, on the environment and suggests ways to reduce those impacts. The main study is divided into sections discussing the environmental aspects, of the industry, related to raw materials, the manufacturing process, the packaging stage and discarding the equipment, i.e., generation of e-waste.*
Keywords *-Electronic Equipment, Environmental Impacts, E-waste, Packaging.*

I. Introduction

Technological advancement has been a major driver of progress and development. A rapid evolving and growing electronics industry is a necessity for continual improvement. The word 'electronics' refers to various types of equipment which involve but are not limited to computers, telephones, television, audio equipment and digital cameras.For the manufacture of electronics, the environment is exploited and after use, most of the constituents are returned to the environment, either directly or after applying certain treatment. Hence, e-waste is a growing problem.The sections of the paper help to understand the environmental impacts of the life cycle of electronics.

II. Literature Review

1.1 Raw Materials

Rapid changes in technology, coupled with falling prices and planned obsolescence, has led to rapidly growing demand for electrical and electronic devices.

The components which constitute the electronic devices are made up of certain processed raw materials. These components, such as capacitors, use metals like copper, aluminium, silver etc. andpetroleum based products, the most common being plastic. Metals are preferred for their conductivity and plastic for its heat resisting properties. Other materials used include ceramics, silicon and cobalt.

Mining for minerals can have adverse effects on the environment. These include erosion, loss of biodiversity, and contamination of water resources, soil. At times, mining is accompanied with additional forest logging in the vicinity.

Mineral exploration optimization is an important aspect for environment protection."The optimization of selection of ore deposit types and regions of search, the first task of an exploration planner, is based upon univariate stochastic models of the economic, geometric and occurrence characteristics of deposits supplemented by statistical testing requiring MANOVA and ANOVA models, ...The optimization of mineral exploration is carried out through the use of quantitative models which aim at representing the various stages of the mineral exploration sequence as faithfully as possible,but in a simplified manner..... "[1]

1.2 Manufacturing Process

Evaluating the environmental impacts of processes involved in production of electronic devices/ components is often difficult due to diverse inputs and outputs involved. Hence to form a better understanding we will be taking the example of semiconductors, a widely recognized and used constituent of most electrical and electronic devices. The same manufacturing issues are associated with most of the other constituents of electrical and electronic devices.[2]

2.2.1Environmental impacts included in the manufacturing of these constituents include:

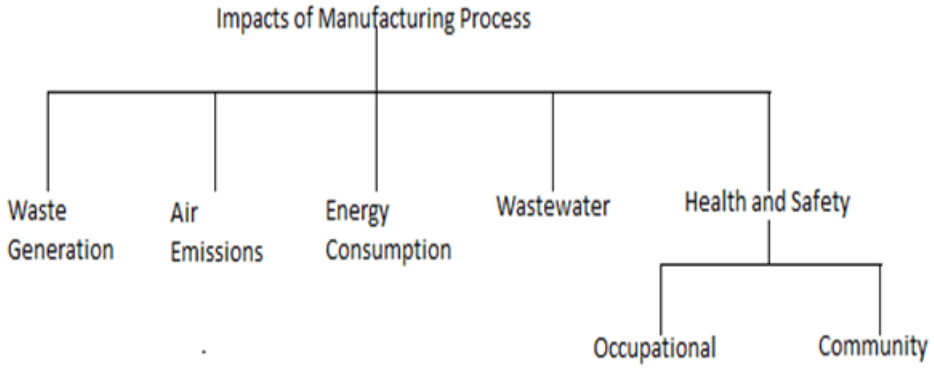

Fig.1 Impacts of Manufacturing Process

(a) Waste generation: Almost all steps involved in manufacturing lead to generation of waste, like spent epoxy material, which is generated in the manufacturing of semiconductors and PCBs. The environmental impacts can be prevented by techniques such as: process modification, raw material substitution, waste segregation and substance recovery. Also proper method and equipment is to be put in place for waste handling and disposal.

(b)Air Emissions: Substances such as volatile organic compounds (VOCs), acid fumes etc., which are toxic and corrosive in nature are to be given special attention. Greenhouse gases are also a nuisance. Diffusion and cleaning processes are the major contributors off all these emissions at the manufacturing stage. Scrubbers are preferable for tackling this issue. In some cases, equipment that can handle high flow rates might be required. Greenhouse gases can be controlled by enhancing energy efficiency, promoting forestry, carbon capture technologies, increasing use of renewable forms of energy, etc. There is always scope for emission-specific solutions. For example, VOC emissions can be controlled by installing regenerative thermal oxidizers as an add-on controlling device.

(c)Energy Consumption: With highly mechanized processes involved energy consumption is bound to be high for manufacturing semiconductor and related devices. Hence, optimal energy consumption becomes a necessity. This can be achieved while reducing the impact on the environment, caused due to other reasons, as stated above. What this means is that reduced energy consumption can be achieved in collaboration with advanced abatement efficiency.

(d) Wastewater: Wastewater may contain organic as well as inorganic substances. These include metals, cyanides, suspended solids, etc. Reuse is important to conserve the resource and reduce potential discharge impacts.For treatment of the wastewater, from the manufacturing process, source segregation and pre-treatment need to be considered as important. Further, units need to be involved for purposes like, reduction in heavy metal, chemical oxidation, dewatering and disposal of residuals. But these units need to be installed keeping in mind the processes involved in the manufacture. In some cases, additional control techniques, for example membrane filtration, activated carbon, etc., might be required.

Before moving on to occupational health and safety, PCBs also require some attention. A printed circuit board (PCB) is used in an electronic device to connect electronic components. This connection is made using conductive tracks, pads and various other features.

Many methods have been developed to reduce the environmental impact of PCB production. This includes improvements in the manufacturing process, like for cleaning and preparation of the surface, non-chelating cleaners can be used and the reuse of cleaners can be done. Also for etching, use differential plating and pattern versus panel plating. And ion exchange technologies can help in metal recovery.

(e) Occupational Health and Safety: The occupational health and safety hazards included in the manufacturing process include exposure to hazardous chemicals (such as acids, bases, metal powder, etc.) and materials released by substrates. To protect workers from the effects of exposure, substitution of hazardous materials can be considered. Also, gas detectors and other detection& alarm systems should be installed. Material specific protection should be looked into, which can involve isolated, automated systems and also engineering controls (such as ventilation systems).Precautions like periodically cleaning clothes and preferring wet processes, to avoid the dust nuisance, are also necessary.

Community Health and Safety: Community health and safety is also to be taken into consideration by the organization and the entities undertaking the manufacturing process, as this may have impact beyond the life of the project. Water quality, fire safety, traffic safety, disease prevention and emergency preparedness are some of the issues which fall in this category and vary according to the manufacturing process. [3,4]

2.2.2 Power saving and Eco-labels

In1992, the U.S.EPA introduced the Energy Star symbol. Energy Star power management features help in order to reduce the amount of energy consumed by various computer systems. Buyers must ensure that this symbol is present, when they buy the device. Apart from lower energy consumption, the Energy Star symbol ensures the use of technology which increases efficiency and hence the life of the device. The devices which have these systems, that are Energy Star qualified, are not expensive when compared to the devices without these systems. [5]

Eco-labels are for environmental performance certificates. In contrast to self-claimed performances, these labels are provided by an impartial third party. Eco-labels generally represent more than simple power saving technologies. Eco-labels are issued based on overall performance efficiency and proven environmental preference. [6]

1.3 Packaging

An important but often overlooked aspect of the electronics industry, which can have an impact on the environment, is the packaging. The disposal issue with packaging material is well understandable. Paper and plastic are the most used materials for packaging.Over the years, with changing shapes & sizes of devices, and for enhancing the appeal of the device, organizations, manufacturing these devices, have constantly being changing the way they pack these devices. The material used, at times, is non-biodegradable and toxic in nature.But with growing concern for the environment around the globe and organizations understanding their role, there have been many innovations, which without overlooking the safety and appeal factor for the device, are minimising the impact of the organization on the environment and also promoting environment conservation.

The properties which make a packaging material environment-friendly include biodegradability, recyclability and reusability. Also, the manufacturing process of the packaging material helps determine its overall environmental impact. The packaging can be optimized by designs which require less material.

An innovative methodology used by the company Dell,is the application of bamboo as a packaging solution. They use it for cushioning some lightweight products. Dell bamboo packaging is certified as compostable which also implies its biodegradability. Other advantages of bamboo are good strength, good durability and recyclability. Also, it is easy to grow bamboo and growing bamboopromotes health soil by preventing soil erosion. [7]

Another lightweight and odourless packaging solution, which is biodegradable, is thermocol. Thermocol, a packaging solution having customized finishes, has a cushioning property that avoids damages. Also, it is insulated and resistant against fungus.

Recycled paper and cardboard boxes should be promoted, as paper products are generally considered not to be environment friendly. The inks, used for decoration, should also be environment friendly.

1.4 E-waste

E-waste can be defined as electrical and electronic equipment, which includes all components that are part of the product at the time of discarding. [8]

1.4.1 Constituents of e-waste

Electronic devices that can be hazardous include televisions, CRT computer monitors, LCD screens. But the list is not limited to this.

Though electrical and electronic equipment contains components that are hazardous, they do not pose a threat to the environment until it reaches the stage of discarding, after which it is considered e-waste and what follows is processing and disposal. For example, one can consider the cathode ray tubes (CRTs) of computer monitors. These contain heavy metals such as lead, cadmium and barium. These heavy metals can be very harmful to the health (human respiratory and nervous system) and environment if they enter the waste stream. [9] Apart from this, e-waste also contains non-hazardous substances such as tin, copper, aluminium etc.In addition to these, electronic items containvaluable materials. This includes, for example, gold and silver. Gold is used with respect to connector plating, primarily in computer equipment. [10]

1.4.2 Quantity of e-waste

An important thing to note is that a large number of equipment labelled e-waste is not waste in the true sense. But it is rather equipment or components that can be reused or recycled, which can lead to material recovery. 50 million metric tons of e-waste is estimated to reach dumps every year.The US-EPA has estimated an increase in the quantity of e-waste generated globally. Something more surprising and a cause of concern is only around 13% of this current quantity is recycled. Also it is estimated that amount of e-waste generated globally will reach 65m tonnes by 2017.[11]

Also international trade of waste helps developed countries to dump e-waste in developing countries for disposal and treatment. Though many regulations have been formulated to avoid developed countries from dumping toxic waste (by first screening the waste) into developing countries, but it is still considered easy for them to dump the toxic waste, to save money, in the name of recycling.In India, e-waste handling and recycling is mostly done by the informal sector. Being informal, they do not have proper techniques and knowledge to handle the e-waste. Hence, processing occurs at a very rudimentary level. This leads to risk of harm to human health and environment. Fair trade involving cooperation can lead to creation of sustainable jobs. This can also bring affordable technology to countries, with high repair and reuse activities. [12,13]

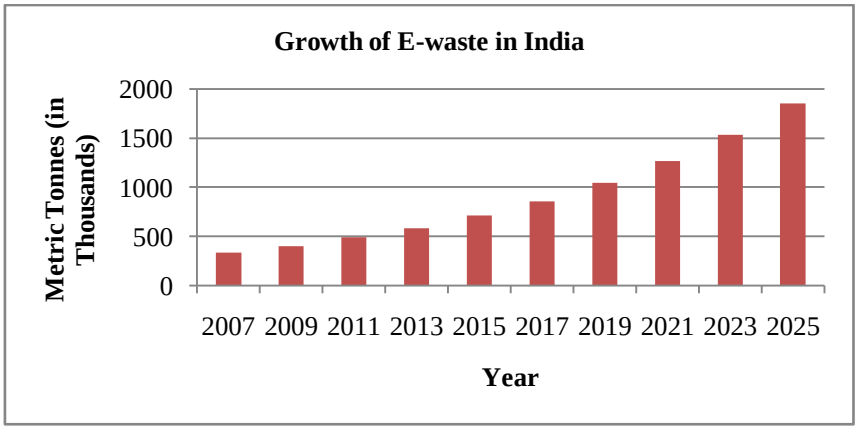

Fig.2 Growth of E-waste in India [14]

1.4.3 E-waste management

Optimizing e-waste management can help in conserving natural resources and money, a lot of which goes into manufacturing of the equipment. According to a UN study, to manufacture one computer and a screen, it requires at least 22 kg of chemicals, 240 kg of fossil fuels and 1.5 tonnes of water (Kuehr and Williams, 2003). Also, according to the EPA, recycling 1 million cell phones can recover about 24 kg (50 lb) of gold, 250 kg (550 lb) of silver, 9 kg (20 lb) of palladium, and more than 9,000 kg (20,000 lb) of copper. [15]

(a) Incineration: Incineration involves burning to destroy the waste. In the case of e-waste, which contains toxic substances, incineration can lead to dispersion of these substances into the environment. Toxicity is not limited to the gases released but also the residue ash is harmful to the health and environment. When flame retardants are incinerated, dioxin formation is catalysed by copper, present in PCBs and cables. Inhalation of emissions released from incineration of e-waste (with no prior treatment) can lead to acute respiratory problems and also chronic health related issues. For example, the burning of PVC, which releases hydrogen chloride. On mixing with water in the lungs it forms hydrochloric acid. This formation can lead to many respiratory complications and corrosion of lung tissues.

Many valuable elements, which could have been recovered, are lost due to incineration with no prior treatment. Prior treatment is important. Particle size, temperature and availability of sufficient oxygen help in optimizing the incineration process. Flue gas purification is also considered helpful in addition to prior treatment.

The incineration process can be optimized by certain measures:

i. Consider other rapid oxidation options where nutrient recovery is viable.
ii. Segregation prior to incineration.
iii. Capturing usable energy which is produced.
iv. Reuse possibility of ash.
v. Flexible scalability to avoid unnecessary demand-side growth. [16]

(b) Landfills: Though landfills are widely used, they are prone to leakage. This is true for even the best ones, in the long run. The leachate which contains toxic materials can easily pollute the ground and water resources. Uncontrolled dumping also poses the threat of hazardous emissions. When circuit breakers are destroyed, mercury may leach. Landfills are also prone to uncontrolled fires.To optimize landfilling separating toxic materials and those which have possibilities of recycling, is helpful. Good quality landfills which follow standards of environment safety should be used.

(c)Recycling: Columnist Steve Lohr, in April 1993, published the first major report on the recycling of electronic waste. Recycling involves sorting, dismantling and recovery. Recovery refers to the recovery of valuable materials. For example, the printed circuit boards contain precious metals (like gold, silver, etc.) and base metals (like copper, iron, etc.). One way of recovery involves melting the circuit boards, burning cable sheathing for recovering the copper wire and the open pit acid leaching for separating valuable metals. The conventional method of mechanical shredding and separation has low recycling efficiency. Alternative methods for recycling of PCBs are being studied. One such method is cryogenic decomposition.

Consumers can play their part by sending devices back to the manufacturers or to a recycler. Corporate recycling involves companies being responsible for compliance with regulations. In America, under the Resource Conservation and Recovery Act, this practice is to be followed even if the recycling process is outsourced. Information security is considered an important aspect in these cases.

There are companies that not only take care of data protection and security but also follow green disposal procedures and help improve the environment. Many of these companies have been started by amateur recyclers, facing the issue of unemployment. They help in stripping, components of electronics, of their most valuable components, leading to recovery of metals like aluminium, gold, palladium, etc. As an economic incentive, the processing charge for old devices should be, if possible, included in the sale price of the new device.

Optimized recycling can be considered comprising of these steps:

(i) Removal of critical components: This is done to avoid contamination later. An example of critical component can be CFC gases from refrigerators
(ii) Mechanical processing: This step generally would involve use of crushers, shredders, magnetic- and air-separators. This type of processing is done to recover recyclable material and remove remaining fractions of hazardous substances.
(iii) Refining: This is important before final disposal or for recovery of substances which can be used as secondary raw materials. Glass and plastics are given importance at this stage. [17]

The gas emissions are also to be filtered.

Recycling can be beneficial to a larger extent with responsible methods. These methods consider health, safety and environmental aspects.

(d) Reuse: Reuse is an alternative to recycling. Reuse extends the lifespan of a device. Though eventual recycling is needed but reuse helps postpone recycling.There are environmental as well as social benefits connected with reuse, such as diminished use of landfills, diminished demand for raw material and new devices etc. The option for sale and donating electronics is available for the consumers. Though information security is an issue, some organizations are working which not only help in pick up but also wipe the data clean and give estimates of the devices` value. Another way is through online auctions.

Manufacturers can offer free replacement and pickup services to customers wanting to purchase a new device. There also exist organizations which work in purchasing and recycling old and broken devices from individuals and corporations.

2.4.4 Issues and Regulations

Though there exist regulations and increased concern over environmental harm, but still unscreened e-waste still gets exported from mature economies to developed countries. 'The Basel Convention on the Control of Trans boundary Movements of Hazardous Wastes and Their Disposal' is a treaty which was designed as a way of reducing transfer of hazardous wastefrom developed to developing economies.Guiyu, in China, is sometimes referred to as the e-waste capital of the world. It is a huge e-waste processing area, which has over 150,000 e-waste workers. The work they do involve activities such as snipping cables, dipping circuit boards in acid baths, etc. They cause problems like ground water contamination and air pollution due to activities such as uncontrolled burning, disassembly and disposal. Such activities also lead to occupational safety and health issues. Another important issue to be understood is that even in ecology-responsible regions of the world, there is a widening gap between the equipment sold and the e-waste collected.[18,19]

'The Restriction of Hazardous Substances Directive 2002/95/EC, RoHS, short for Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, was adopted in February 2003 by the European Union.' The directive is designed for the removal of six hazardous materials (lead, mercury, cadmium, hexavalent chromium, poly-brominated biphenyls and poly-brominated di-phenyl ether) in the manufacture process of electronic and electrical equipment.

Another notable directive is the WEEE Directive. 'The Waste Electrical and Electronic Equipment Directive (WEEE Directive) is the European Community directive 2002/96/EC on waste electrical and electronic equipment (WEEE) which, together with the RoHS Directive 2002/95/EC, became European Law in February 2003. The WEEE Directive set collection, recycling and recovery targets for all types of electrical goods, with a minimum rate of 4 kilograms per head of population per annum recovered for recycling by 2009.' It made the manufacturers focus on the material content of new equipment that they were putting forward for the customer, in the market.

"E-Cycling" is an initiative for management of e-waste. It refers to reuse, shredding and general collection of used devices/electronics. This concept has been introduced by the United States Environmental Protection Agency. It also involves the process of disassembling, repairing and recycling of whole or components of the e-waste. E-cycling facilities have been gaining attention. This can be attributed to technology's rapid rate of obsolescence and opportunities for manufacturers to influence the market of used products.There have been supports as well as criticism towards the e-cycling concept. One opposition to this concept is that many dangerous problems are associated with the disassembly process, apart from it being costly.[20]

III. Conclusion

Due to the nature of production of electronics and disposal of e-waste, it can be said that the problem is of global concern. The tendency of electronics and waste being hazardous in nature poses a threat to humans and the environment. Unregulated treatment procedures have low efficiency, due to focus on few valuable substances, and harmful for the environment. Apart from new and improved techniques, which promote resource efficiency at the manufacturing as well as disposal stage, what is required is public, corporate and government cooperation. With already limited resources being used up and huge amounts of e-waste getting dumped every year, the world needs measures for continued production in a sustainable manner and safe disposal of the waste. The annual e-Day initiative by Computer Access New Zealand (CANZ) can be considered one such step towards sustainability. The initiative is about raising awareness about e-waste and promoting environment friendly disposal.

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