GREEN COMPUTING

The Impact of Managing Electronic Waste

. Introduction

Electronic waste or **e-waste** describes discarded electrical or electronic devices. Used electronics which are destined for refurbishment, reuse, resale, salvage recycling through material recovery, or disposal are also considered e-waste.

Informal processing of e-waste in developing countries can lead to adverse human health effects and environmental pollution.

Electronic scrap components, such as CPUs, contain potentially harmful materials such as lead, cadmium, beryllium, or brominated flame retardants. Recycling and disposal of e-waste may involve significant risk to health of workers and their communities

E-waste or electronic waste is created when an electronic product is discarded after the end of its useful life.

The rapid expansion of technology and the consumption driven society results in the creation of a very large amount of e-waste in every minute.

In the last years, there is an increasing acknowledgment of our impact on the environment due to our lifestyle, while the need to adopt a more sustainable approach concerning our consumption habits emerges as of particular significance.

This trend regards industrial sectors affecting the consumption habits and, especially, electronic industry where the short life cycles and the rapidly developing technology have led to increased e-waste volumes. The majority of e-waste elements are led to landfills.

However, their partial recyclability, due to their material composition along with the unavoidable restrictions in landfills, has led to the development of retrieval techniques for their recycling and re-use, highlighting the significance of e-waste recycling, not only from a waste management aspect but also from a valuable materials' retrieval aspect.

\E-waste is often misinterpreted as related to old computers or IT equipment in general, while the synonymous term Waste Electrical and Electronic Equipment (WEEE) is also used in the international literature

The European WEEE Directive classifies waste in ten categories: Large household appliances (including cooling and freezing appliances), Small household appliances, IT equipment (including monitors), Consumer electronics (including TVs), Lamps and Luminaires, Toys, Tools, Medical devices, Monitoring and control instruments and Automatic dispensers.

These include used electronics which are destined for reuse, resale, salvage, recycling, or disposal as well as re-usable (working and repairable electronics) and secondary raw materials (copper, steel, plastic, etc.).

The term "waste" is reserved for residue or material which is dumped by the buyer rather than recycled, including residue from reuse and recycling operations, because loads of surplus electronics are frequently commingled (good, recyclable, and non-recyclable).

Several public policy advocates apply the term "e-waste" and "e-scrap" broadly to all surplus electronics. Cathode ray tubes (CRTs) are considered one of the hardest types to recycle

On the other hand, the Partnership on Measuring ICT for Development defines e-waste into six categories, namely:

(1) Temperature exchange equipment (e.g., air conditioners, freezers),

(2) Screens, monitors (e.g., TV, laptop),

(3) Lamps (e.g., LED lamps),

(4) Large equipment (e.g., washing machines, electric stoves),

(5) Small equipment (e.g., microwave, electric shaver), and

(6) Small IT and telecommunication equipment (e.g., mobile phones, printers).

(7) Products in each category vary in longevity profile, impact, and collection methods, among other differences.

CRTs have a relatively high concentration of lead and phosphors (not to be confused with phosphorus), both of which are necessary for the display.

The United States Environmental Protection Agency (EPA) includes discarded CRT monitors in its category of "hazardous household waste" but considers CRTs that have been set aside for testing to be commodities if they are not discarded, speculatively accumulated, or left unprotected from weather and other damage.

These CRT devices are often confused between the DLP Rear Projection TV, both of which have a different recycling process due to the materials of which they are composed.

The EU and its member states operate a system via the European Waste Catalogue (EWC) - a European Council Directive, which is interpreted into "member state law". In the UK, this is in the form of the List of Wastes Directive.

However, the list (and EWC) gives a broad definition (EWC Code 16 02 13*) of what is hazardous electronic waste, requiring "waste operators" to employ the Hazardous Waste Regulations (Annex 1A, Annex 1B) for refined definition. Constituent materials in the waste also require assessment via the combination of Annex II and Annex III, again allowing operators to further determine whether a waste is hazardous.

Debate continues over the distinction between "commodity" and "waste" electronics definitions. Some exporters are accused of deliberately leaving difficult-to-recycle, obsolete, or non-repairable equipment mixed in loads of working equipment (though this may also come through ignorance, or to avoid more costly treatment processes).

Protectionists may broaden the definition of "waste" electronics in order to protect domestic markets from working secondary equipment.

The high value of the computer recycling subset of electronic waste (working and reusable laptops, desktops, and components like RAM) can help pay the cost of transportation for a larger number of worthless pieces than what can be achieved with display devices, which have less (or negative) scrap value. In A 2011 report, "Ghana E-Waste Country Assessment", found that of 215,000 tons of electronics imported to Ghana, 30% were brand new and 70% were used. Of the used product, the study concluded that 15% was not reused and was scrapped or discarded.

This contrasts with published but uncredited claims that 80% of the imports into Ghana were being burned in primitive conditions

Review of literature

Safe management of electronic and electrical waste (e-waste/WEEE) is becoming a major problem for many countries around the world. In particular, developing countries face a number of issues with the generation, transboundary movement and management of e-waste.

The key to success in terms of e-waste management is to develop eco-design devices, properly collect e-waste, recover and recycle material by safe

methods, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries, and raise awareness of the impact of e-waste.

No single tool is adequate but together they can complement each other to solve this issue. A national scheme such as EPR is a good policy in solving the growing e-waste problems.

This work is a part of a wider study involving the economic and environmental implications of managing construction and demolition waste (CDW), focused on the operation of a large scale CDW recycling plant.

This plant, to be operated in the Lisbon Metropolitan Area (including the Setubal peninsula), is analyzed for a 60-year period, using primary energy consumption and CO_2eq emission impact factors as environmental impact performance indicators.

Simplified estimation methods are used to calculate industrial equipment incorporated, and the operation and transport related impacts.

Material recycling – sorted materials sent to other industries, to act as input – is taken into account by discounting the impacts related to industrial processes no longer needed.

This first part focuses on calculating the selected impact factors for a base case scenario (with a 350 tones/h installed capacity), while a sensitivity analysis is provided in part two. Overall, a 60-year global primary energy consumption of 71.4 thousand toe (tone of oil equivalent) and a total CO_2eq emission of 135.4 thousand tones are expected.

Under this operating regime, around 563 thousand toe and 1465 thousand tones CO_2eq could be prevented by replacing raw materials in several construction materials industries (e.g.: ferrous and non-ferrous metals, plastics, paper and cardboard). It is estimated that the world generates around 20–50 million tons of e-waste annually, most of it from Asian countries. Improper handling of e-waste can cause harm to the environment and human health because of its toxic components.

Several countries around the world are now struggling to deal with this emerging threat. Although the current emphasis is on end-of-life management of e-waste activities, such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention.

Environmentally sound management (ESM) of e-waste in developing countries is absent or very limited. Transboundary movement of e-waste is a major issue throughout the region. Dealing with the informal recycling sector is a complex social and environmental issue.

There are significant numbers of such challenges faced by these countries in achieving ESM of e-waste. This article aims to present a review of challenges and issues faced by Asian countries in managing their e-waste in a sustainable way.

Electronic waste (e-waste) is one of the fastest-growing pollution problems worldwide given the presence of a variety of toxic substances which can contaminate the environment and threaten human health, if disposal protocols are not meticulously managed.

This paper presents an overview of toxic substances present in e-waste, their potential environmental and human health impacts together with management strategies currently being used in certain countries.

Several tools including Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA) and Extended Producer Responsibility (EPR) have been developed to manage e-wastes especially in developed countries.

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Highlights

► The main environmental impacts prevented derive from virgin material replacement.
► They can be up to 10 times those generated from the CDW recycling operation.
► This figure relates to industrial processes and includes transportation needs.
► Another issue is CO_2eq. emission savings in operating a CDW recycling plant.
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The amount of electronic waste worldwide

E-waste is considered the "fastest-growing waste stream in the world" with 44.7 million tones generated in 2016- equivalent to 4500 Eiffel towers.

In 2018, an estimated 50 million tons of e-waste was reported, thus the name 'tsunami of e-waste' given by the UN. Its value is at least $62.5 billion annually.

Rapid changes in technology, changes in media (tapes, software, MP3), falling prices, and planned obsolescence have resulted in a fast-growing surplus of electronic waste around the globe.

Technical solutions are available, but in most cases, a legal framework, a collection, logistics, and other services need to be implemented before a technical solution can be applied.

Display units (CRT, LCD, LED monitors), processors (CPU, GPU, or APU chips), memory (DRAM or SRAM), and audio components have different useful lives.

Processors are most frequently outdated (by software no longer being optimized) and are more likely to become "e-waste" while display units are most often replaced while working without repair attempts, due to changes in wealthy nation appetites for new display technology.

This problem could potentially be solved with modular smartphones or Phonebooks.

These types of phones are more durable and have the technology to change certain parts of the phone making them more environmentally friendly.

Being able to simply replace the part of the phone that is broken will reduce e-waste. An estimated 50 million tons of E-waste are produced each year.

The USA discards 30 million computers each year and 100 million phones are disposed of in Europe each year.

The Environmental Protection Agency estimates that only 15–20% of e-waste is recycled; the rest of these electronics go directly into landfills and incinerators.

In 2006, the United Nations estimated the amount of worldwide electronic waste discarded each year to be 50 million metric tons.

According to a report by UNEP titled, "Recycling – from E-Waste to Resources," the amount of e-waste being produced – including mobile phones and computers – could rise by as much as 500 percent over the next decade in some countries, such as India.

The United States is the world leader in producing electronic waste, tossing away about 3 million tons each year. China already produces about 2.3 million tons (2010 estimate) domestically, second only to the United States. And, despite having banned e-waste imports. China remains a major e-waste dumping ground for developed countries.

Society today revolves around technology and by the constant need for the newest and most high-tech products we are contributing to a mass amount of e-waste.

Since the invention of the iPhone, cell phones have become the top source of e-waste products because they are not made to last more than two years Electrical waste contains hazardous but also valuable and scarce materials. Up to 60 elements can be found in complex electronics.

As of 2013, Apple has sold over 796 million I Devices (iPod, iPhone, iPad). Cell phone companies make cell phones that are not made to last so that the consumer will purchase new phones.

Companies give these products such short lifespans because they know that the consumer will want a new product and will buy it if they make it.

In the United States, an estimated 70% of heavy metals in landfills comes from discarded electronics

While there is agreement that the number of discarded electronic devices is increasing, there is considerable disagreement about the relative risk (compared to automobile scrap, for example), and strong disagreement whether curtailing trade in used electronics will improve conditions, or make them worse.

According to an article in *Motherboard*, attempts to restrict the trade have driven reputable companies out of the supply chain, with unintended consequences.

E Waste Data from 2016 onwards

In 2016, Asia was the territory that brought about by significant the most extensive volume of e-waste (18.2 Mt), accompanied by Europe (12.3 Metric ton), America (11.3 Metric ton), Africa (2.2 Metric ton), and Oceania (0.7 Metric ton).

The smallest in terms of total e-waste made, Oceania was the largest generator of e-waste per citizen (17.3 kg/inch), with hardly 6% of e-waste cited to be gathered and recycled.

Europe is the second broadest generator of e-waste per citizen, with an average of 16.6 kg/inch; however, Europe bears the loftiest assemblage figure (35%). America generates 11.6 kg/inch and solicits only 17% of the e-waste caused in the provinces, which is commensurate to the assortment count in Asia (15%)

. However, Asia generates fewer e-waste per citizen (4,2 kg/inch). Africa generates only 1.9 kg/inch, and limited information is available on its collection percentage.

The record furnishes regional breakdowns for Africa, Americas, Asia, Europe, and Oceania.

The phenomenon somewhat illustrates the modest number figure linked to the overall volume of e-waste made that 41 countries have administrator e-waste data.

For 16 other countries, e-waste volumes were collected from exploration and evaluated. The outcome of a considerable bulk of the e-waste (34.1 Metric tons) is unidentified.

In countries where there is no national e-waste constitution in the stand, e-waste is possible interpreted as an alternative or general waste. This is land-filled or recycled, along with alternative metal or plastic scraps.

There is the colossal compromise that the toxins are not drawn want of accordingly, or they are chosen want of by an informal sector and converted without well safeguarding the laborers while venting the contaminations in e-waste.

Although the e-waste claim is on the rise, a flourishing quantity of countries are embracing e-waste regulation.

National e-waste governance orders enclose 66% of the world population, a rise from 44% that was reached in 2014.

E-Waste legislative frameworks

Looking at European continent, European Union has addressed the issue of electronic Waste by introducing two pieces of legislation. The first legislation, named "The Directive on waste electrical and electronic equipment or WEEE directive entered into force in 2003.

The main aim of this directive was to regulate and motivate electronic waste recycling and re-use in member states at that moment.

This regulative was revised in 2008, and the new WEEE directive came into force in 2014.

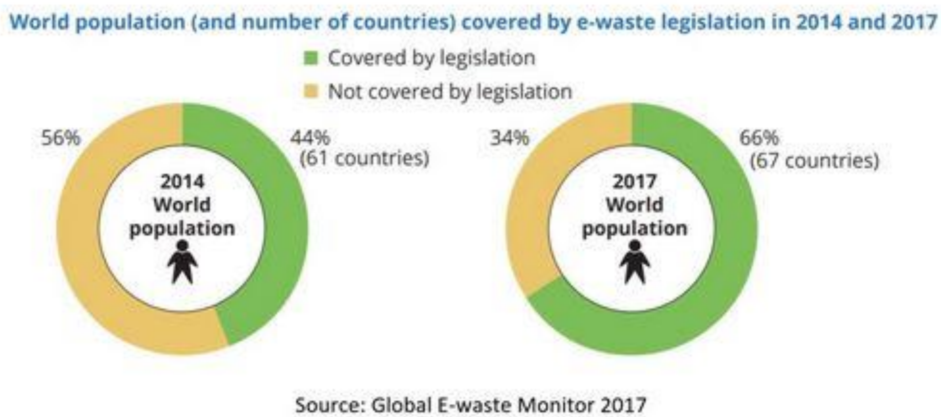
Furthermore, European Union has also implemented the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment in 2003.

This document was additionally revised in 2012.

When it comes to Western Balkan countries, North Macedonia has adopted a Law on Batteries and Accumulators in 2010, followed by the Law on Management of electrical and electronic equipment in 2012. Serbia has regulated management of special waste stream, including electronic waste, by National waste management strategy (2010-2019).

Montenegro has adopted Concessionary Act concerning electronic waste with ambition to collect 4 kg of this waste annually per person until 2020.

Albanian legal framework is based on the draft act on waste from electrical and electronic equipment from 2011 which focuses on the design of electrical and electronic equipment. Contrary to this, Bosnia and Herzegovina are still missing a law regulating electronic waste.



Union Regulations on e-waste

European Union has addressed the E-waste issue by adopting several directives on the matter. In 2011 an amendment was made to a 2003 Directive 2002/95/EC regarding restriction of the use of hazardous materials in the planning and manufacturing process in the EEE.

In the 2011 Directive, 2011/65/EU it was stated as the motivation for more specific restriction on the usage of hazardous materials in the planning and manufacturing process of electronic and electrical devices as there was a disparity of the EU Member State laws and the need arose to set forth rules to protect human health and for the environmentally sound recovery and disposal of WEEE. (2011/65/EU, (2)) The Directive lists several substances subject to restriction.

The Directive states restricted substances for maximum concentration values tolerated by weight in homogeneous materials are the following: lead (0,1 %); mercury (0,1 %), cadmium (0,1 %), hexavalent chromium (0,1 %), polybrominated biphenyls (PBB) (0,1 %) and polybrominated diphenyl ethers (PBDE) (o,1 %).

If technologically feasible and substitution is available, the usage of substitution is required.

There are, however, exemptions in the case in which substitution is not possible from the scientific and technical point of view. The allowance and duration of the substitutions should take into account the availability of the substitute and the socioeconomic impact of the substitute. (2011/65/EU, (18))

The European Union Directive 2012/19/EU regulates the WEEE and lays down measures to safeguard the ecosystem and human health by inhibiting or shortening the impact of the generation and management of waste of WEEE. (2012/19/EU, (1)) The Directive takes a specific approach to the product design of EEE. It states in Article 4 that Member States are under the constraint to expedite the kind of model and manufacturing process as well as cooperation between producers and recyclers as to facilitate re-use, dismantling and recovery of WEEE, its components, and materials. (2012/19/EU, (4)) The Member States should create measures to make sure the producers of EEE use eco-design, meaning that the type of manufacturing process is used that would not restrict later re-use of WEEE.

The Directive also gives Member States the obligation to ensure a separate collection and transportation of different WEEE. Article 8 lays out the requirements of the proper treatment of WEEE.

The base minimum of proper treatment that is required for every WEEE is the removal of all liquids. The recovery targets set are seen in the following figures.

Bu the Annex I of Directive 2012/19/EU the categories of EEE covered are as follows:

1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment and photovoltaic panels
5. Lightning equipment
6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7. Toys, leisure and sports equipment
8. Medical devices (with the exception of all implanted and infected products)
9. Monitoring and control instruments
10. Autonomic dispensers

Minimum recovery targets referred in Directive 2012/19/EU starting from 15 August 2018:

WEEE falling within category 1 or 10 of Annex I
- 85% shall be recovered, and 80% shall be prepared for re-use and recycled;
WEEE falling within category 3 or 4 of Annex I
- 80% shall be recovered, and 70% shall be prepared for re-use and recycled;
WEEE falling within category 2, 5, 6, 7, 8 or 9 of Annex I
-75% shall be recovered, and 55% shall be prepared for re-use and recycled;
For gas and discharged lamps, 80% shall be recycled.

Growth in the IT and communication sectors has enhanced the usage of the electronic equipment exponentially. Faster upgradation of electronic product is forcing consumers to discard old electronic products very quickly, which, in turn, adds to e-waste to the solid waste stream. The growing problem of e-waste calls for greater emphasis on recycling e-waste and better e-waste management.

Electronic waste or e-waste is generated when electronic and electrical equipment become unfit for their originally intended use or have crossed the expiry date. Computers, servers, mainframes, monitors, compact discs (CDs), printers, scanners, copiers, calculators, fax machines, battery cells, cellular phones, transceivers, TVs, iPods, medical apparatus, washing machines, refrigerators, and air conditioners are examples of e-waste (when unfit for use)

. These electronic equipment’s get fast replaced with newer models due to the rapid technology advancements and production of newer electronic equipment. This has led to an exponential increase in e-waste generation. People tend to switch over to the newer models and the life of products has also decreased.

E-waste typically consists of metals, plastics, cathode ray tubes (CRTs), printed circuit boards, cables, and so on. Valuable metals such as copper, silver, gold, and platinum could be recovered from e-wastes, if they are scientifically processed.

The presence of toxic substances such as liquid crystal, lithium, mercury, nickel, polychlorinated biphenyls (PCBs), selenium, arsenic, barium, brominated flame retardants, cadmium, chrome, cobalt, copper, and lead, makes it very hazardous, if e-waste is dismantled and processed in a crude manner with rudimentary techniques

. E-waste poses a huge risk to humans, animals, and the environment. The presence of heavy metals and highly toxic substances such as mercury, lead, beryllium, and cadmium pose a significant threat to the environment even in minute quantities.

Consumers are the key to better management of e-waste. Initiatives such as Extended Producer Responsibility (EPR); Design for Environment (DfE); Reduce, Reuse, recycle (3Rs), technology platform for linking the market facilitating a circular economy aim to encourage consumers to correctly dispose their e-waste, with increased reuse and recycling rates, and adopt sustainable consumer habits.

In developed countries, e-waste management is given high priority, while in developing countries it is exacerbated by completely adopting or replicating the e-waste management of developed countries and several related problems including, lack of investment and technically skilled human resources. In addition, there is lack of infrastructure and absence of appropriate legislations specifically dealing with e-waste. Also, there is inadequate description of the roles and responsibilities of stakeholders and institutions involved in e-waste management, etc.

In 2016, the Ministry of Environment, Forest and Climate Change (MDeC) released the updated E-waste (Management) Rules, which came in supersession of the E-waste in India (GOI, 2016).

Global E-Waste Problem

International treaties such as Basel Convention aim at reducing and regulating the movement of hazardous waste between nations. Even with the Convention, illegal shipment and dumping of e-wastes continue to take place.

It is estimated that 50 million tones of e-waste were generated globally in 2018. Half of this is personal devices such as computers, screens, smartphones, tablets, and TVs, with the remainder being larger household appliances and heating and cooling equipment.

Despite 66 per cent of the world's population being covered by e-waste legislation, only 20 per cent of global e-waste is recycled each year, which means that 40 million tons of e-waste is either burned for resource recovery or illegally traded and treated in a sub-standard way.

In the US alone, more than 100 million computers are thrown away with less than 20 per cent being recycled properly. China discards 160 million electronic devices a year. In the past, China has been regarded as the largest e-waste dumping site in the world.

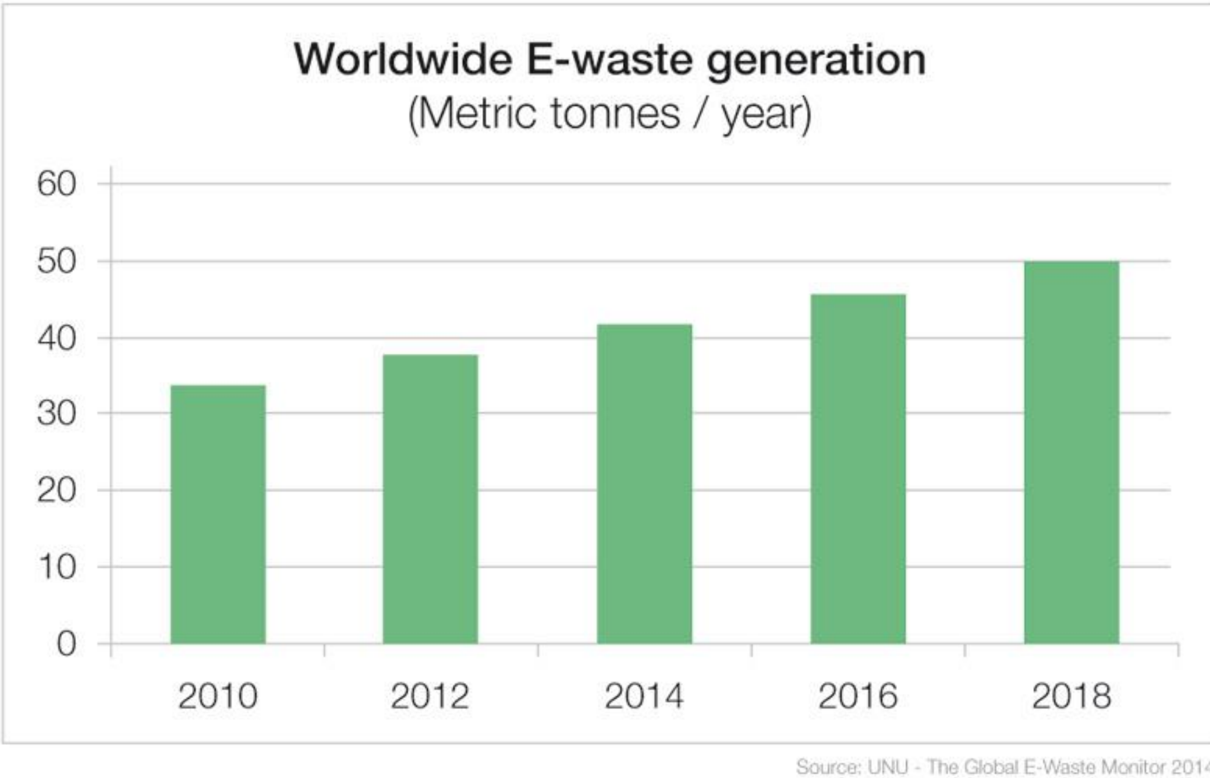
Hundreds of thousands of people have expertise in dismantling electronic junk.

The rate at which the e-waste volume is increasing globally is 5 per cent to 10 per cent yearly. In India, the volume of e-waste generated was 146,000 tones per year (Borthakur and Sinha, 2013).

However, these data only include e-waste generated nationally and do not include waste imports (both legal and illegal) which are substantial in emerging economies such as India and China. The reason is that large amount of waste electrical and electronic equipment (WEEE) enters India from foreign countries.

Switzerland is the first country in the world to have established and implemented a formal e-waste management system that has recycled 11 kg/capita of e-waste against the target of 4 kg/capita set by the European Union (EU).

In the EU, the EU WEEE directive clearly imposes collection, recovery, and recycling targets on its member countries. Thus, it stipulates a minimum collection target of 4 kg/capita per year for all the member states.



These collection- and weight-based recycling targets seek to reduce the amount of hazardous substances disposed into landfills and to increase the availability of recyclable materials that indirectly encourages less virgin materials consumption in new products.

One-third of electrical and electronic waste in the EU is reported as separately collected and appropriately treated. The introduction of the EPR scheme in 2003 was the most important step in South Korea, and about 70 per cent of e-waste was collected by producers.

Over the same period, the amount of e-waste reused and recycled was 12 per cent and 69 per cent, respectively. The remainder was sent to landfill sites or incineration plants, accounting for 19 per cent.

The lax or zero enforcement of existing regulatory framework or low level of awareness and sensitization, and inadequate occupational safety for those involved in these processes exacerbate e-waste management in developing countries compared to the EU and Japan, which have well-developed initiatives at all levels aimed at changing consumer behavior.

Therefore, there is need for developing countries to adopt effective strategies to encourage re-use, refurbishing or recycling e-waste in specialized facilities to prevent environmental contamination and human health risks.

China, Peru, Ghana, Nigeria, India, and Pakistan are the biggest recipients of e-waste from industrialized countries (Mmereki, et al., 2016).

The Basel Action Network (BAN) aims to ensure that e-waste is dealt with in an environment-friendly manner. It safeguards the planet from toxic waste trade. The BAN, Silicon Valley Toxic Coalition (SVTC), and Electronics Take-Back Coalition (ETBC) constitute an associated network of environmental advocacy NGOs in the US.

The three organizations' common objective is to promote national-level solutions for hazardous waste management.

A recent initiative has been e-Stewards, a system for auditing and certifying recyclers and take back programmers so that conscientious consumers know which ones meet high standards.

E-Waste Problem in India

India ranks 177 amongst 180 countries and is amongst the bottom five countries on the Environmental Performance Index 2018, as per a report released at the World Economic Forum 2018. This was linked to poor performance in the environment health policy and deaths due to air pollution categories.

Also, India is ranked fifth in the world amongst top e-waste producing countries after the USA, China, Japan, and Germany and recycles less than 2 per cent of the total e-waste it produces annually formally.

Since 2018, India generates more than two million tones of e-waste annually, and also imports huge amounts of e-waste from other countries around the world. Dumping in open dumpsites is a common sight which gives rise to issues such as groundwater contamination, poor health, and more.

The Associated Chambers of Commerce and Industry of India (ASSOCHAM) and KPMG study, Electronic Waste Management in India identified that computer equipment account for almost 70 per cent of e-waste, followed by telecommunication equipment phones (12 per cent), electrical equipment (8 per cent), and medical equipment (7 per cent) with remaining from household e-waste.

E-waste collection, transportation, processing, and recycling is dominated by the informal sector. The sector is well networked and unregulated.

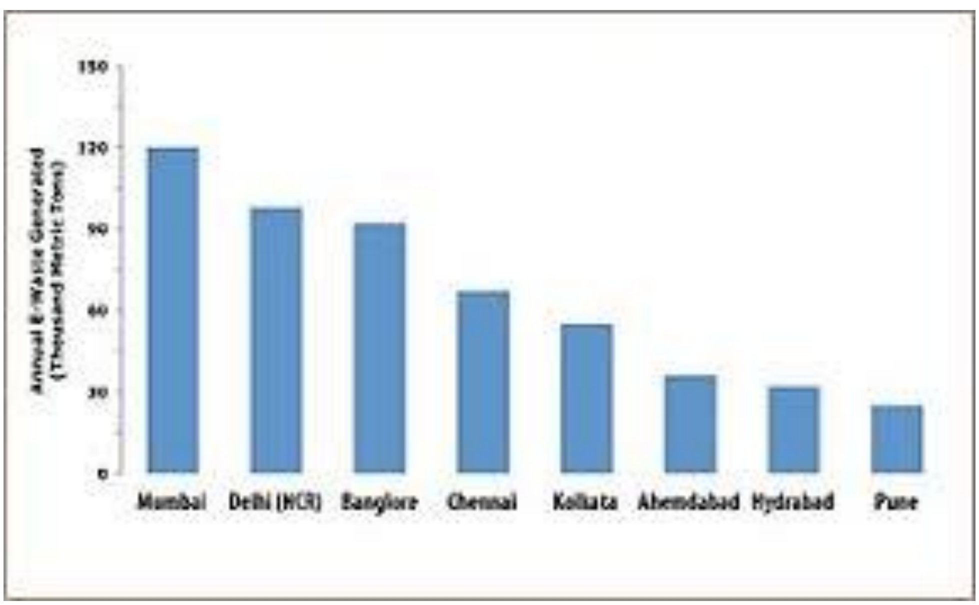
Often, all the materials and value that could be potentially recovered is not recovered. In addition, there are serious issues regarding leakages of toxins into the environment and workers' safety and health.

Seelampur in Delhi is the largest e-waste dismantling center of India. Adults as well as children spend 8–10 hours daily extracting reusable components and precious metals like copper, gold and various functional parts from the devices.

E-waste recyclers use processes such as open incineration and acid-leeching. This situation could be improved by creating awareness and improving the infrastructure of recycling units along with the prevalent policies.

The majority of the e-waste collected in India is managed by an unorganized sector.

Also, informal channels of recycling/reuse of electronics such as repair shops, used product dealers, e-commerce portal vendors collect a significant proportion of the discarded electronics for reuse and cannibalization of parts and components.



Impact of Recycling E-Waste in Developing World

Almost all e-wastes contain some form of recyclable material, including plastic, glass, and metals; however, due to improper disposal methods and techniques these materials cannot be retrieved for other purposes.

If e-waste is dismantled and processed in a crude manner, its toxic constituents can wreak havoc on the human body. Processes such as dismantling components, wet chemical processing, and incineration are used to dispose the waste and result in direct exposure and inhalation of harmful chemicals. Safety equipment such as gloves and face masks are not widely used, and workers often lack the knowledge and experience required to carry out their jobs properly.

In addition to this, manual extraction of toxic metals leads to entering of dangerous material in the bloodstream of the individual doing so. The health hazards range from kidney and liver damage to neurological disorders. Recycling of e-waste scrap is polluting the water, soil, and the air. Burning to retrieve metal from wires and cables has led to the emission of brominated and chlorinated dioxins as well as carcinogens which pollute the air and, thereby, cause cancer in humans and animals.

Toxic chemicals that have no economic value are simply dumped during the recycling process. These toxic chemicals leach into underground aquifer thereby degrading the local groundwater quality and rendering the water unfit for human consumption as well as agricultural purposes. When e-waste is dumped in landfills, the lead, mercury, cadmium, arsenic, and PCBs make the soil toxic and unfit for agricultural purposes.

Very recent studies on recycling of e-waste has pointed towards increasing concentrations of PCBs, dioxins and furans, plasticizers, bisphenol-A (BPA), polycyclic aromatic hydrocarbons (PAH), and heavy metals in the surface soil of the four metro cities of India, that is, New Delhi, Kolkata, Mumbai, and Chennai where e-waste is being processed by the informal sectors (Chakraborty et al., 2018 and 2019).

In those studies, it has been observed that the sites engaged in metal recovery processes are the prime sites for such persistent toxic substances. Studies from the same group also reported that the persistent organic pollutants produced or released during the recycling process are escaping in the ambient air due to their semi-volatile nature.

It is estimated that 50 million tones of e-waste were generated globally in 2018. Half of this is personal devices such as computers, screens, smartphones, tablets, and TVs, with the remainder being larger household appliances and heating and cooling equipment.

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practices, Toxics Link 16. www.nokia.com/in- end/about-nokia A recent study about the rising electronic pollution in the USA revealed that the average computer screen has five to eight pounds or more of Lead representing 40 percent of all the lead in US landfills. All these toxins are persistent, bioaccumulate toxins (PBTs) that create environmental and health risks when computers are incinerated, put in landfills or melted down. The emission of fumes, gases, and particulate matter into the air, the discharge of liquid waste into water and drainage systems, and the disposal of hazardous wastes contribute to environmental degradation.

The processes of dismantling and disposing of electronic waste in developing countries led to a number of environmental impacts as illustrated in the graphic. Liquid and atmospheric releases end up in bodies of water, groundwater, soil, and air and therefore in land and sea animals – both domesticated and wild, in crops eaten by both animals and human, and in drinking water.

One study of environmental effects in Guiyu, China found the following:

- Airborne dioxins – one type found at 100 times levels previously measured
- Levels of carcinogens in duck ponds and rice paddies exceeded international standards for agricultural areas and cadmium, copper, nickel, and lead levels in rice paddies were above international standards
- Heavy metals found in road dust – lead over 300 times that of a control village's road dust and copper over 100 times

The Agbogbloshie area of Ghana, where about 40,000 people live, provides an example of how e-waste contamination can pervade the daily lives of nearly all residents. Into this area—one of the largest informal e-waste dumping and processing sites in Africa—about 215,000 tons of secondhand consumer electronics, primarily from Western Europe, are imported annually. Because this region has considerable overlap among industrial, commercial, and residential zones, Pure Earth (formerly Blacksmith Institute) has ranked Agbogbloshie as one of the world's 10 worst toxic threats (Blacksmith Institute 2013).

A separate study at the Agbogbloshie e-waste dump, Ghana found a presence of lead levels as high as 18,125 ppm in the soil. US EPA standard for lead in soil in play areas is 400 ppm and 1200 ppm for non-play areas.

Scrap workers at the Agbogbloshie e-waste dump regularly burn electronic components and auto harness wires for copper recovery, releasing toxic chemicals like lead, dioxins and furans into the environment.

Researchers such as Brett Robinson, a professor of soil and physical sciences at Lincoln University in New Zealand, warn that wind patterns in Southeast China disperse toxic particles released by open-air burning across the Pearl River Delta Region, home to 45 million people.

In this way, toxic chemicals from e-waste enter the "soil-crop-food pathway," one of the most significant routes for heavy metals' exposure to humans. These chemicals are not biodegradable— they persist in the environment for long periods of time, increasing exposure risk.

In the agricultural district of Chachoengsao, in the east of Bangkok, local villagers had lost their main water source as a result of e-waste dumping. The cassava fields were transformed in late 2017, when a nearby Chinese-run factory started bringing in foreign e-waste items such as crushed computers, circuit boards and cables for recycling to mine the electronics for valuable metal components like copper, silver and gold.

But the items also contain lead, cadmium and mercury, which are highly toxic if mishandled during processing. Apart from feeling faint from noxious fumes emitted during processing, a local claimed the factory has also contaminated her water. "When it was raining, the water went through the pile of waste and passed our house and went into the soil and water system.

Water tests conducted in the province by environmental group Earth and the local government both found toxic levels of iron, manganese, lead, nickel and in some cases arsenic and cadmium. "The communities observed when they used water from the shallow well, there was some development of skin disease or there are foul smells," founder of Earth, Pincham Seating said.

"This is proof, that it is true, as the communities suspected, there are problems happening to their water sources

The environmental impact of the processing of different electronic waste components

E-Waste Component	**Process Used**	**Potential Environmental Hazard**
Cathode ray tubes (used in TVs, computer monitors, ATM, video cameras, and more)	Breaking and removal of yoke, then dumping	Lead, barium and other heavy metals leaching into the ground water and release of toxic phosphor
Printed circuit board (image behind table – a thin plate on which chips and other electronic components are placed)	De-soldering and removal of computer chips; open burning and acid baths to remove metals after chips are removed.	Air emissions and discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury
Chips and other gold-plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	PAHs, heavy metals, brominated flame retardants discharged directly into rivers acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air

		emissions of brominated dioxins, heavy metals, and PAHs
Plastics from printers, keyboards, monitors, etc.	Shredding and low temp melting to be reused	Emissions of brominated dioxins, heavy metals, and hydrocarbons
Computer wires	Open burning and stripping to remove copper	PAHs released into air, water, and soil.

Depending on the age and type of the discarded item, the chemical composition of E-waste may vary. Most E-waste are composed of a mixture of metals like Cu, Al and Fe. They might be attached to, covered with or even mixed with various types of plastics and ceramics. E-waste has a horrible effect on the environment and it is important to dispose it with an R2 certifies recycling facility. Some major impacts of E-waste on environment are,

· Toxic materials like lead, zinc, nickel, flame retardants, barium and chromium, found in computers and most electronics, if released into the environment, can cause damage to human blood, kidneys as well as central and peripheral nervous system.

· The damage caused by warming up of E-waste releasing toxic chemicals into the air and damaging the atmosphere is one of the biggest environmental impacts from E-waste. This will result in number of airborne diseases and increase the toxicity of air, making it unfit for breathing and living.

· The electronic waste, which often gets thrown out into landfills, release toxins, which seep into ground water. This affects both land and sea animals. Especially in developing countries, where most of the electronic waste is dumped in landfills, also affects the health of the people. This contamination of soil will also result in loss of vegetation and affecting the ecosystem.

· The electronic waste which is created via cell phones, especially in countries like United States, where most Americans get new cell phones every 12 to 18 months. And only 10 percent of these cell phones are recycled.

This creates more and more E-waste with lack of responsible recycling, the environmental issues of E-waste are continually increasing. Mobile phones are "considered hazardous waste" in California; many chemicals in such phones leach from landfills into the groundwater system.

· In places like Guiyu, China, which receives shipments of toxic E-wastes from all over the world, the largest E-waste disposal site, many people living around here often exhibit substantial digestives, neurological, respiratory and bone problems.

. Global Significance of e-Waste

e-Waste has raised concerns because many components in these products are toxic and do not biodegrade easily if at all. Based on these concerns, many European countries banned e-Waste from landfills in the 1990s

. Ming Hong et al. found alarming levels of dioxin compounds, linked to cancer, developmental defects, and other health problems; in samples of breast milk, place mat, and hair, these compounds are linked to improper disposal of electronic

products. Furthermore, surveys have indicated that much exported US e-Waste is disposed of unsafely in developing countries, leaving an environmental and health problem in these regions [

The European Union has legislation requiring manufacturers to put in place e-Waste disposal mechanisms (Wanjiku,)

Due to the difficulty and cost of recycling used electronics, as well as, lackluster enforcement of legislation regarding e-Waste exports, large amounts of digital discards are transported internationally from various industrialized countries to certain destinations where lower environmental standards and working conditions make processing e-Waste more profitable[17].Impacts from those countries, especially Asia, have already been reported.

Meanwhile, recycling and disposal of e-Waste are also growing in regions beyond Asia, particularly in certain African countries.

Force of an international accord, known as the Basel Convention, has banned the export of hazardous waste to poorer countries since 1992, but the practice continues as pointed out by Chris Carroll (Woodall, [9, 10]). Commonly, the term "bridging the digital divide" issued when old WEEE are exported to developing countries.

They are often labeled as "second-hand goods" since export of reusable goods is allowed. However, EU Commission estimates that anywhere between 25–75 percent of second-hand goods exported to Africa are broken and cannot be reused [20].

On the other hand, most WEEE that do work on arrival only have a short second life and/or are damaged during transportation. On the other hand, illegal disposal sometimes occurs in the name of charitable donation according to United Nations Environment Program (UNEP).

Recently, a report from ToxicsLinkrevealsthat70percentofWEEEdisposed in New Delhi of India was imported from developed countries.

Current Challenges for e-Waste Elimination

In many cases, the cost of recycling e-Waste exceeds the revenue recovered from materials especially in countries with strict environment regulations. Therefore, e-Waste mostly ends up dumped in countries where environmental standards are low or nonexistent and working conditions are poor.

Historically Asia has been a popular dumping ground, but as regulations have tightened in these countries, this trade has moved to other regions, particularly West Africa. Most developing countries lack the waste removal infrastructure and technical capacities necessary to ensure the safe disposal of hazardous waste.

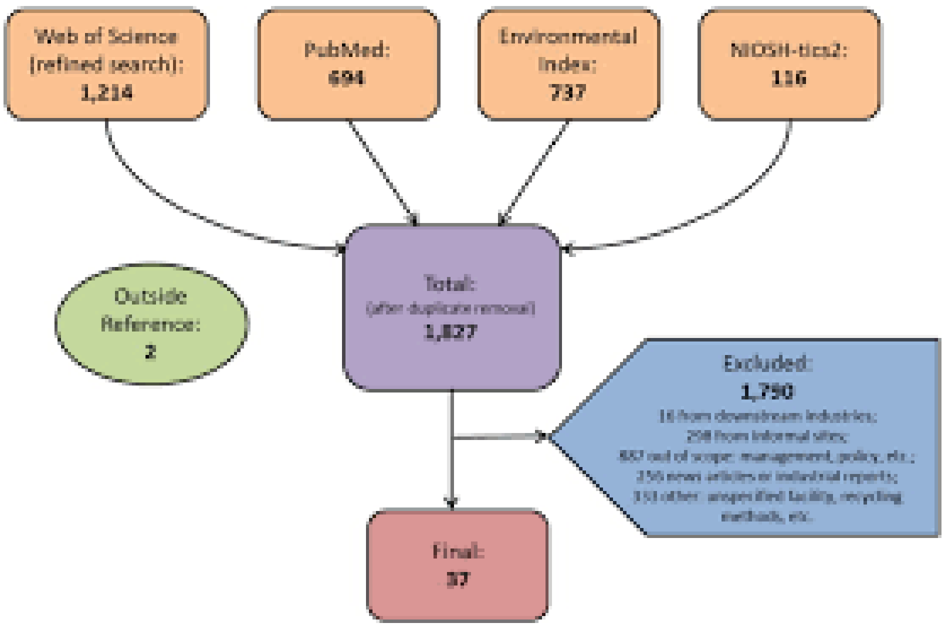
e-Waste has been linked to a variety of health problems in these countries, including cancer, neurological and respiratory disorders, and birth defects. Therefore, the fight against illegal imports of WEEE has become one of the major challenges. From another perspective, some regulations, which have been established to handle e-Waste, are often limited since they exclude many hazardous substances that are used in electronics.

Moreover, many regulations simply fail to address the management of e-Waste. Osinbajo states that in Africa, for example, there is a highly ineffective infrastructure for e-Waste management.

More precisely, there is no well-established system for separation, sorting, storage, collection, transportation, and disposal of e-Waste. Even worse, there is little or no effective enforcement of regulations related to e-Waste management and disposal.

Under these circumstances, practical e-Waste management in Africa is unregulated, and rudimentary techniques are widely used. These techniques include manual disassembly of WEEE without concern of the hazardous chemicals, heating printed circuit boards (PCBs) to recover solder and chips, melting and extruding flame-retardant plastics, and burning plastics to isolate metals; generating an average of US $6 worth of material from each computer (Basel Action Network).

This value is not much especially considering the environmental and health costs of burning plastic, sending dioxin and other toxic gases into the air and the large volumes of worthless parts dumped in nearby landfills, allowing the remaining heavy metals to contaminate the area and harm life



Regulations and Market Mechanism

So far, legislation on WEEE is mainly driven by certain European countries and the European Directive on WEEE. Most developing nations are lagging in the development of similar regulations and especially in their enforcement. In most developed countries, legislations and policy guidelines have been developed and established in order to control the use of hazardous chemicals in those products, and the management of e-Waste after they are discarded.

Among these, the most well-known is European Union (EU) restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) Directive, which currently addresses only limited amount of hazardous chemicals commonly used in WEEE, including heavy metals of cadmium, lead, hexavalent chromium, and mercury and certain brominated flame retardants (BFRs). Furthermore, the EU WEEE Directive requires producers to set up systems for the treatment of WEEE.

However, even with these regulations, all hazardous materials that are used in newly manufactured products cannot be fully controlled, and management of e-Waste within the supply chain cannot be fully addressed.

According to one estimate, only 25 percent of the e-Waste in EU is properly collected. And in the US this figure is even lower at only 20 percent. e-Waste legislation in the US is primarily set at the state level with a few stalled efforts in the US Congress.

Normally, unaccounted e-Waste in both regions is exported to non-OECD countries. Although it is illegal in EU, such exports have been classified as legal recycling by US EPA.

Similar e-Waste legislation has been introduced in China and other countries as well. For instance, China has established administrative measures to control the pollution of WEEE. Meanwhile, several multinational collaboration agreements are currently taking shape to prohibit or limit the shipment of hazardous waste, including e-Waste, from industrialized to developing counties.

Those include the Stockholm Convention on Persistent Organic Pollutants (POPs), the Rotterdam Convention on the Prior Informed

Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, and the Ban Amendment of the UN Basel Convention. Despite the existence of those conventions, there is still a relatively high flow of WEEE from the US, Canada, Europe, Japan, and Korea to developing countries such as China, India, Pakistan, and several African countries , while some of those developing countries themselves are becoming the fastest growing markets for EEE and are currently generating large amount of WEEE .

Looking at South Africa as an example, there is no specific legislation currently to deal with e-Waste. However, the new National Environmental Management Waste Bill includes implications for e-Waste management, aiming to reform waste management legislation in South Africa in order to protect public health and the environment.

Furthermore, a national waste information system is envisaged as well. In addition to these legislative- and convention-based initiatives, another policy option is to extend the WEEE producers' responsibility for their products over the entire lifecycle, of the product, from design—to use—to disposal.

The concept of Extended Producer Responsibility (EPR) is defined as "the producer's responsibility for a product is extended to the postconsumer stage of a product's life cycle"

. EU is a good example of this. For instance, Switzerland has a decade-long experience of applying EPR to manage its e-Waste.

. Current Approaches

When it comes to e-Waste, recycling faces a number of challenges, including dealing with hazardous materials such as CRT glass and finding markets for flame-retardant plastics. Furthermore, no technology currently exists for recycling certain EEE in an environmentally friendly manner.

In the US, the US EPA estimates that as much as three quarters of the computers sold are stockpiled in garages and closets. When thrown away, they either end up in landfills or incinerators or are exported to Asia.

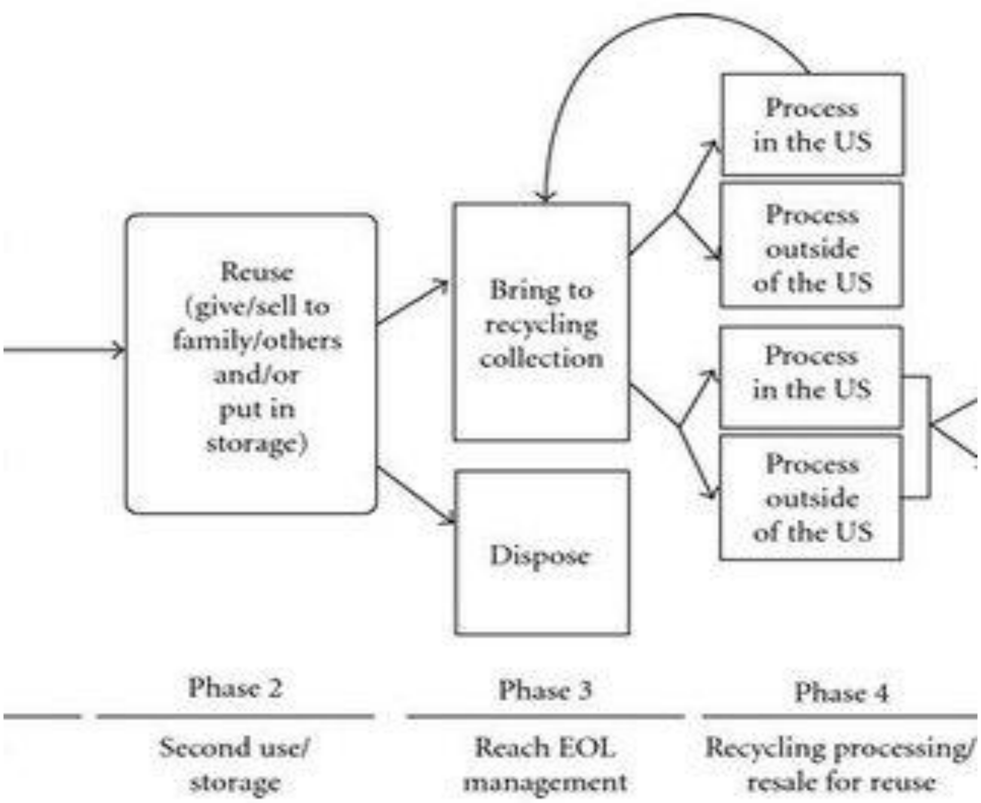
Table 1 enumerates a few places where e-waste ends up. In 2005, more than 2 million tons of e-Waste were generated in the US alone (US EPA), but only 17 to 18 percent of that was collected for recycling. The rest, more than80 percent, was disposed of, largely in local landfills.

The hazardous materials in e-Waste can leach out of the landfills into ground water and streams, and if the plastic components are burned, dioxins are emitted into the air

. Moreover, it is estimated that 50–80 percent of the e-Waste collected for recycling in the US is actually exported to developing countries, even though it is illegal for most of those countries to accept this toxic waste stream.

Much of this illegally traded waste is going to the informal recycling sectors in many Asian and West African countries, where it is dismantled or disposed of using very primitive and toxic technologies [34]. On the other hand, cost is another big issue for e-Waste management.

Cost of logistics and transportation is a challenge faced by most recyclers, preventing the flow of waste volumes in the country.



<u>Places where e-Waste ends up.</u>

Landfill:

According to the US EPA, more than 4.6 million tons of e-Waste ended up in landfills in 2009. Toxic chemicals in electronics products can leach into the land over time or be released into the atmosphere, impacting nearby communities and the environment.

Incineration:

This process releases heavy metals such as lead, cadmium, and mercury into the atmosphere and which can bioaccumulate in the food chain, particularly in fish, which is the major source of exposure for the general public.

Reuse:

This is a good way to increase a product's lifespan. Many old products are exported to developing counties. Although the benefits of reusing electronics in this way are clear, the practice is causing serious problems because the old products are dumped after a short period of use in areas that are unlikely to have hazardous waste facilities.

Recycle:

Although recycling can be a good way to reuse the raw materials in a product, the hazardous chemicals in e-Waste mean that electronics can harm workers in the recycling yards, as well as their neighboring communities and the environment.

Export:

E-Waste is routinely exported by developed countries, often in violation of the international law. Inspections of 18 European seaports in 2005 found that as much as 47 percent of waste destined for export, including e-Waste, was illegal.

At least 23,000 metric tons of undeclared or "grey" market electronic waste was illegally shipped in 2003 to the Far East, India, Africa, and China. In the USA, it is estimated that 50–80 percent of the waste collected for recycling is being exported in this way.

This practice is legal because the USA has not ratified the Basel Convention

e-Waste Estimation Techniques

In order to predict the number of units and the tons of e-Waste for the targeted years, Microsoft Excel was used to apply linear regression technique. Framework for modeling the product lifecycle is illustrated in.

For Phase 1, we assembled product sales data, as well as data on the average weight of products by year. The model considered product sales from 1980 through 2007 and predicted the annual quantity needing end-of-life (EOL) management through 2007.

. Estimating the Quantity of EOL Products Generated That Are Recycled versus Disposed. The modeling effort resulted in estimates of the quantity of products that are generated annually for EOL management. EOL management consists of recycling or disposal.

This corresponds to the two options

in Phase 3 of Figure 1: “Dispose” or “Bring to Recycling Collection.” Disposal was estimated as the difference between what was generated for EOL management and what was recycled.

. Estimating the Portion of EOL Electronics Recycled. Recycling of consumer electronics includes the recovery of products by municipal and other collection programs for materials separation and recovery, as well as reuse in both domestic and foreign end markets.

It also includes businesses and institutions contracting directly with electronic recyclers for recycling services of their EOL equipment. Donation organizations also collect EOL electronic equipment for reuse or recycling. The term “reuse” in the EOL management stage refers to products entering the recycling materials management system that are in working order and can be resold “as is” or refurbished for resale by electronics recyclers and dismantlers.

The reuse of consumer electronics before they enter the management system (i.e., products that pass between individual users) is assumed to occur prior to EOL management.

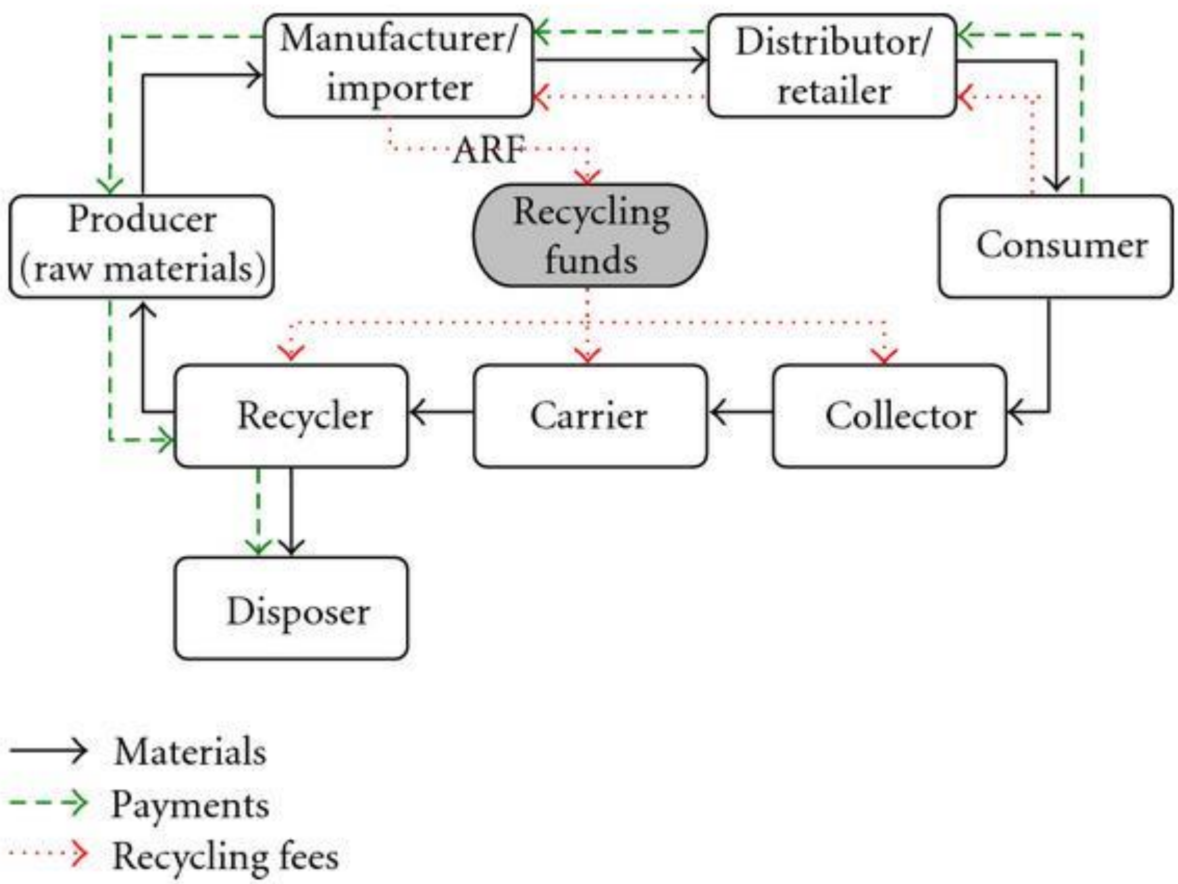
Estimating the Portion of EOL Electronics Disposed. To estimate the portion of the estimated EOL electronics generated every year that is disposed, we subtracted the amount estimated to be recycled from the estimated amount generated for EOL management. Table 2 includes the disposal estimates for 1999 through 2007.

According to this analysis, 18.4 percent, by weight, of the EOL electronics generated in 2007 were collected for recycling. During the time period 1999 through 2005, even though the amount of material being recycled increased, the amount of EOL products generated kept pace such that the percentage of material being recycled remained relatively constant.

A larger gain in the recycling rate has been estimated for 2006 and 2007.Implementation overstated ecteronic recovery and disposal regulations has provided a boost to the electronics recycling industry. The majority of EOL material that is not being recycled is probably mostly going into landfills [35]. Table 3 shows the prediction of EOL through 2015.

As can be seen, EOL grows from a meager 159 million units in 1999 to a 615.2 million units in 2015, emphasizing the need to seriously tackle this issue.

: Flow of materials and finances in the Swiss e-Waste management system, source



e-Waste Management in Industry Fore-

Waste management systems, some of the most successful examples can be found in countries such as Switzerland and the Netherlands

. Experience of the Swiss e-Waste management system is shown as an example in this paper. Generally, the Swiss e-Waste management system can be viewed as an ERP-based system, where each stakeholder has their own clear definition of role and responsibilities.

the solid black line indicates the material flow in the e-Waste management system. In order to optimize the closed loop of material flow, raw materials are first converted into EEE products by manufacturers, then end-of-life products after going through retail and consumption are collected and recycled to produce new goods.

Besides recycling, other materials which cannot be recycled go to incineration for energy recovery, and a small portion goes to landfill, approximately 2%. Payments as well as recycling fees, shown as green and red lines, respectively, indicate financial flow of the system. Producer responsibility Organizations (PROs), such as SWICO and SENS, collect advanced recycling fees (ARF) from producers on their sale or import of an appliance.

Then, ARF are passed down to retailers or distributors who invoice consumers for their purchase of new appliance. This ARF is used to pay for the whole e-Waste recycling system, including collection, distribution, dismantling, sorting, decontamination, and recycling of the disposed EEE products

. According to a study by Hewlett-Packard (HP), the Global Digital Solidarity Fund (DSF), and the Swiss Federal Laboratories for Materials Testing and Research (Emma), most countries in Africa lack legislative mechanisms to tackle the problem of e-Waste and have not yet recognized it as a hazardous waste stream.

However, several pilot projects have been initiated in Africa to show that recycling can provide both employment opportunities for local communities and act as a step towards a sustainable solution for tackling e-Waste (Wanjiku,).

For instance, a pilot project in Cape Town initiated by HP processed 60 metric tons of electronic equipment in 10 months in 2008, generating an income of about $14,000 and creating direct employment for 19 people

This project also tried to incorporate informal processing activities that proved highly effective in dealing with waste.

This team is expected to launch the second phase of this project, to engage corporate and government partners to further extend e-Waste management programs to other countries and to tackle the problem in the entire continent (Wanjiku,). Gregory et al. proposed an e-Waste take-back system, whose main functions are collection, processing, system management, and financing scheme.

Meanwhile, several examples of current system models have been presented including California, Maine, and Minnesota in the US, and Belgium, France, and Germany, in the EU. Even though some successful stories of e-Waste take-back system currently exist, but sever all challenges still remain including

(I) how to balance the harmonization between manufacturers and recyclers with respect to finance, operations, technologies, and so forth,

(ii) how to deal with different business models of stakeholders from various industries,

(iii) how to determine the amount of policy in law, leaving others to be industrial standards, (iv) how to ensure that obligations are met by the stakeholders.

Table 2: Distribution of used and EOL products

	Total EOL products		Total recycled			Total disposed		
Year	Units (mill)	Tons (000)	Units (mill)	Tons (000)	Ton (%)	Units (mill)	Tons (000)	Ton (%)
1999	159	1,056	23.6	157	14.9	135.4	899.2	85
2000	161.6	1282	24	190	14.8	137.7	1092	85
2001	193.6	1447.6	28.1	210	14.5	165.5	1237.6	85
2001	225.2	1634	34.6	250	15.3	190.7	1384	85
2003	273.8	1944.7	40.8	290	14.9	232.9	1654.7	85
2004	310.7	2043.5	48.6	320	15.7	262	1723.5	84
2005	342.1	2172.6	54.3	345	15.9	287.8	1827.6	84
2006	342.9	2107.8	61.3	377	17.9	281.5	1730.8	82
2007	372.7	2251.7	68.5	414	18.4	304.2	1837.7	82
2008	412.6	2527.1	72.4	441.2	18	340.1	2088	83
2009	441.5	2674.7	78.2	471.9	18.4	363.2	2205.4	82
2010	470.5	2822.9	84	502.6	18.8	386.3	2322.8	82
2011	499.4	2970.5	89.8	533.3	19.2	409.4	2440.3	82
2012	528.4	3118.7	95.6	564	19.1	432.5	2557.7	82
2013	557.3	3266.3	101.5	595.3	19.9	455.6	2675.1	81
2014	586.3	3414.5	107.3	626	20.3	478.7	2792.5	81
2015	615.2	3562.1	113.1	656.7	20.7	501.8	2909.9	81

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Source [36].

An estimation of e-waste:

The exponential growth of internet users from 501 million in 2006 to over 1.3 billion at in 2011 in developing countries clearly indicates that the sale of computers and other terminals has grown at a lightning pace. In 2006, 44% of internet users were in developing countries whereas in 2011, 62%, were present in developing countries.

Personal computer sales have significantly increased from 2000 to 2010, from about 170 million units sold globally in 2000 to about 370 million units sold in 2010.

It is projected that sales in 2014 will reach an estimated 470 million units which is more than double in the last 10 years. In India, it is estimated that approximately 1.42 million PCs are getting obsolete every year.

ITU data release of June 2012 indicates that total number of mobile cellular subscriptions reached almost 6 billion by the end of 2011, and in the developing countries, about 80% of the 660 million new mobile cellular subscriptions added in 2011were generated.

The report "Recycling - from E-Waste to Resources" issued at a meeting of the Basel Convention estimated that, by 2020 in China and South Africa, the e-waste from computers would increase between 200 and 400% over 2007 figures and 500% in India.

It was also estimated that by 2020 in India the amount of e-waste from mobile phones would be 18 times higher than the 2007 figures and 7 times higher in China. Basel Action Network stated that 50- 80% of e-waste generated in USA is exported to India, China, Pakistan, Taiwan and African countries.

UNEP estimates that e-waste is increasing by 40% per year worldwide and e-waste is the fastest-growing type of waste. Between 20 to 50 million metric tons of e-waste are generated worldwide every year, representing more than 5% of urban solid waste, particularly in some developing countries where the volume is expected to grow up to 500 percent over the next decade.

In India, volume of e-waste is estimated to be 0.8 million tons in 2012. According to the Controller and Auditor General's (CAG) report, over 7.2 MT of industrial hazardous waste, 4 lakh tones of electronic waste, 1.5 MT of plastic waste, 1.7 MT of medical waste, 48 MT of municipal waste are generated in the country annually.

Effects of e-waste on human health and environment:

e-waste is highly complex to handle because of its composition.

It is made up of multiple components some of which contain toxic substances that have an adverse impact on human health and environment if not handled properly that is if improper recycling and disposal methods are deployed.

So, there is a need for appropriate technology for handling and disposal of these chemicals.

Basel Convention characterizes e-waste as hazardous when they contain and are contaminated with mercury, lead, cadmium, polychlorinated biphenyl etc.

Wastes containing insulation or metal cables coated with plastics contaminated with or containing lead, coal tar, cadmium, Polychlorinated Biphenyl (PCB) etc. are also characterized as hazardous wastes. Also, precious metal ash from printed circuit boards, glass waste from cathode-ray tubes, LCD screens and other activated glasses are classified as hazardous wastes.

Sr No	Hazardous components	Effect of Hazardous components of e-waste
1	Arsenic	Can affect skin and can decrease nerve conduction velocity. Chronic exposure to arsenic may cause lung cancer and sometimes be fatal.
2	Lead	May affect kidneys, reproductive systems, nervous connections. May cause blood and brain disorders, sometimes may be fatal.
3	Barium	Can affect heart muscle
4	Chromium	Can damage liver, kidneys and may cause asthmatic bronchitis and lung cancer.
5	Beryllium	May cause lung diseases.
6	Mercury	Affects the central nervous system, kidneys and immune system, it impairs fetus growth. May cause brain or liver damage
7	Cadmium	May cause severe pain in the joints and spine. It affects the kidneys and softens bones
8	BFR (Brominates flame retardants)	Can harm reproductive and immune systems, may cause hormonal disorder
9	Chlorofluorocarbon (CFC)	May affect the ozone layer. It may cause skin cancer in human and genetic damage in organisms
10	Polychlorinated Biphenyl (PCB)	May cause cancer in animals, can affect the immune system, reproductive system, nervous system, endocrine system. PCBs persistently contaminate in the environment and cause severe damage

11	Polyvinyl Chloride (PVC)	PVC contains up to 56% chlorine and when burnt, produces Hydrogen chloride gas which in turn produces hydrochloric acid that is dangerous to respiratory system.
12	Dioxin	These are highly toxic to animals and can lead to malfunction of fetus, decreased reproduction and growth rates, affect immune system

Management of e-waste:

There is no unique or ideal model for e-waste management in developing countries, each of which has its own specific environmental, social, technological, economic and cultural conditions.

Environmentally sound management of WEEE recognizes three Rs i.e. reduce, reuse and recycle. The aim would be to reduce the generation of e-waste through smart manufacturing and maintenance, reuse till functioning of electronic equipment by someone else and recycle those components that cannot be repaired.

A smart e-waste management system for developing countries have to assess the e-waste situation, recognize that e-wastes are a complex mixture of hazardous and nonhazardous substances and materials and need to define the integral e-waste management system taking into consideration the EEE market penetration, life cycle of ICT equipment, financing mechanisms etc.

The main aspects to be taken into account when framing ICT waste management guidelines for developing countries are:

- Policy and regulations covering import and export of EEE and WEEE in accordance with the rules of each country and with international legislation

- Defining responsibilities of prime stake holders at the level of government, supply chain, consumers of ICT equipment and entities for disposal of waste

- Extended producer responsibility (EPR) where the manufacturer's responsibility for its ICT equipment extends throughout the various stages of that equipment's life cycle with internalizing the cost of managing the equipment at end of life

- Responsible information system to have data on ICT equipment in market, disused EEE management and WEEE management and to have control on the monitoring and future planning

- Promoting employment and training for the informal sector engaged in recycling and recovery of the materials.

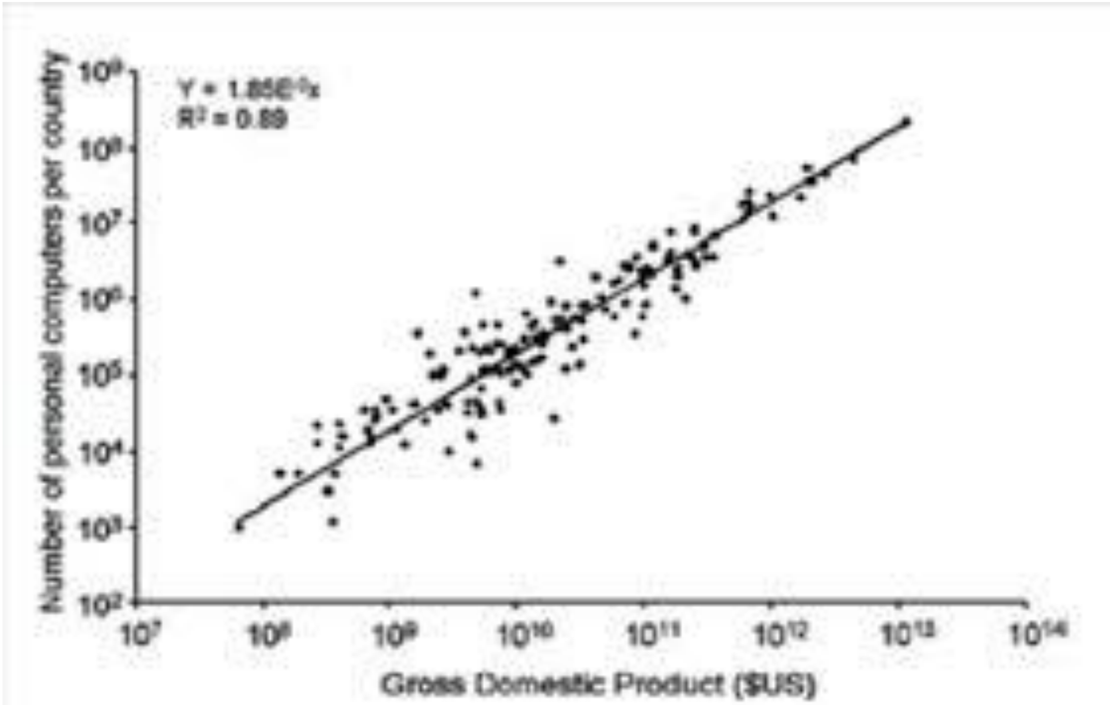
Future trends

The global e-waste production is estimated to increase due to the economic growth and the available technologies since the increased GDP leads to increased purchasing of electronic goods and eventually to increased e-waste production.

For example, the total number of PCs for each country is related to the country's GDP

. The increasing economic growth is anticipated to reflect higher e-waste production

On the contrary, it is anticipated that specific changes in the technology and the consumption habits are expected to decrease the global e-waste production, since consumers may favor more portable PC solutions having 1-3 kg average weight compared to the stationary computer weighing 25 kg, or the stationary computers is expected to be equipped with LCD (Liquid Crystal Display) screens instead of the older CRTs (Cathode Ray Tube).



Y = 1.85E-5x
R² = 0.89
Number of personal computers per country
Gross Domestic Product ($US)

Methodology

The first step in applying any approach and methodology is to establish the geographical boundaries of the study area. The study area included the state boundaries of Delhi, consisting of municipal boundaries, rural and urban areas, and selected areas of the NCR.

The geographical boundaries were fixed considering the location of organized and unorganized markets, places where each item is unloaded, traded, transported, dismantled, recycled, reused, repaired, processed, and disposed of, starting from generation/production to its final end of life.

These places were identified through a transect walk and preliminary surveys in the study area. The two basic approaches applied for carrying out e-waste assessment in the study area involved quantification using material flow analysis (MFA) followed by site-specific validation.

The MFA and site-specific validation help to establish the e-waste trade value chain. The fundamental e-waste trade value chain based on MFA in the study area is shown in Fig. 1. The last three stakeholders in the e-waste trade value chain, consisting of e-waste generation, e-waste processing, and e-waste production/end products, fall in the informal sector.

E-waste processing involves primary dismantling of items from e-waste, e.g., the unscrewing of a PC monitor and removal of the cathode ray tube (CRT) and printed circuit boards.

E-waste production/end products involve processes consisting of secondary dismantling of items obtained as output of e-waste processing, e.g., the rerunning of CRTs, extraction of metals, and others.

The remaining stakeholders fall in the formal sector. This trade value chain has been developed considering that an electronic item “flows” through a region and on its way, it is dismantled and processed in numerous steps until it rejoins the raw material streams or ends in final disposal.

Some of the major stakeholders identified along the flow path include importers, producers/manufacturers, consumers (individual households, business sector), traders, retailers, scrap dealers, disassemblers, and dismantlers.

At each step in the flow, business transactions define the movement of the electronic item in the flow. One of the ways to quantify the flow is through analysis of sales data of these business transactions.

In this study, sales data of electronic items have been applied to a market supply4 calculation method to estimate the theoretical waste arising for each item.

This market supply method has been used consideration taking into data limitations and the short duration of the study. Further, the findings of the field survey also verify the findings obtained from this method.

This method is based on an assumption that 100% of electronic units sold in one particular year will become obsolete at the end of their average life.

Sensitivity analysis was carried out assuming an average life for each item based on market trends and consumer behavior. Sensitivity analysis for PCs was carried out using 5 years and 7 years as the average life. Sensitivity analysis for TVs was carried out using 10 years and 12 years as the average life.

These average lives were fixed based on primary and secondary data from market research agencies and surveys. Further, externalities such as e-waste entering into the study area from outside based on a primary field survey conducted by IRGSSA5 were factored into the final e-waste assessment analysis.

The average life of an electronic item assumed in the sensitivity analysis has been validated through site-specific surveys. The validation has focused on the last three steps, i.e., e-waste generation, e-waste processing, and the production/end products of the e-waste trade value chain.

The basic approach in this validation is to first identify the waste stream, followed by the specific processes in the waste stream; this method included identification and complete tracking of one component in the waste stream.

In this study, the Dismantling of a TV and PC monitor has been taken as the waste stream, in which dismantling the CRT and its rerunning has been taken as a process. In this stream and process, the CRT was identified as one component, which was tracked along the material flow.

Different products, by-products, and waste products handled by stakeholders along the material flow have been identified and quantified. The results obtained from this analysis have been compared with the assumptions to validate the average life of the electronic item.

Material Flow Analysis Unlike the conventional waste (municipal solid waste) e-waste has a different end points for the same good and also the varied discarding patterns.

Therefore, it is difficult to assess what is the waste generation rate from any particular item of electronic gadgets. For instance, a personal computer (PC) bought would have an average life span of 5 years. However, user of PCs would show varying patterns of discarding it after its life span is over.

Some may continue to use it beyond its life time; others may donate it where it is used further for some years. Some may keep in store and others may pass it on to informal recyclers where they would use the useful part for refurbished PCs and other may be subjected to material recovery and final disposal.

This invariably compels researchers to adopt material flow analysis in a life cycle framework in order to estimate the generation of E-Waste. Material flow analysis (MFA) is a process through which the complete flow of material is analyzed in a particular system.

It considers life-cycle approach and is often called “cradle-to-grave” analysis. An accurate material flow analysis along with certain assumptions can give precise e-waste estimate.

Often it is supplemented with other methods or relevant assumptions to estimate e-waste. And all other methods of estimating e-waste do involve material flow analysis of the electrical products as an invariable-step.

Following are the other few methods used in the literature, which may in combination use MFA. Market Supply Method Market supply method estimates e-waste taking into account the data statistics for sales of electronic equipment's and their average life period.

It takes into account two critical assumptions. The first assumption is that particular equipment is discarded as waste once its life span gets over. And this method doesn't take into account the variation in the average life period of the electronic equipment. 387 We consider one variant of the market supply method where we do away with the assumption of no difference in the average life span.

So, in this method, which is an extension of the market supply method, we allow for a substantial difference in the variance in the average life period of the electrical appliances.

The variance depends on the distribution around the average life period and distribution is attained by undertaking survey of the end users. Consumption Use Method Consumption based method consider the data on the stock of the electronic equipment at the household sector. Then, in order to estimate the amount of electronic waste, one need to divide the stock levels by the life span (average) of the equipment.

While estimating stock levels, both penetration level as well as the number of households is taken into account. One can do the similar exercise for industrial sector as well.

Government of India, in its current census (2011), is collecting information on various electronic equipment's such as TV, Radio Transistor, Refrigerator, Air Conditioner etc. at household level.

This data set would make it easier and feasible to conduct this type of analysis for E-Waste estimation in the year to come (Census, 2011).

Econometric Analysis Econometric analysis takes into consideration various factors which affects the estimation of e-waste like GDP of an economy, growth rate of an economy, population of a country, etc. and then tries to estimate e-waste by employing regression tools.

This method would fail to consider the heterogeneous character of consumer behavior and also the life cycle aspects of the analysis which is a key for estimating E-Waste.

Questionnaire Based Survey Another method of estimating e-waste is a questionnaire-based survey. As mentioned in the earlier sections, it is often supplemented by an MFA to complete the process of estimating e-waste. The survey could be conducted on a household basis, commercial establishment basis or even on an industrial basis.

The questions are framed in such a way to collect information about the options of disposing off the electrical appliances, the average year of using an electrical product after re-using, obsolescence rate of different electrical appliances etc. Other methods Time step, Carnegie Mellon (which is a variant of market supply method) method, Batch leaching (which takes into account stock at particular time period) are other methods which are more or less variant of the methods mentioned above are also used to estimate e-waste.

Comparing Various Methods of Estimation Limitation with the material flow analysis is the detailed data requirements, which are extremely difficult to fulfill. Further, the assumptions made on the end-use of electrical appliances could make a big difference in the estimate of waste generation.

Estimates are distinctly sensitive to any variation in the end-use factors.

However, Sensitivity analysis could be employed in a way to control this deviation. Similarly using questionnaire-based survey could also lead to certain problems such as poor response rates experience in such surveys (Stubbing, 2007). In most cases each of these individual methods falls short either on their assumptions or the availability of data.

Therefore, it is proposed that a combination of methods may be employed to have an effective estimate of E-waste.

For instance, an attempt can be made to organize and manage the data on sales of electrical products (Market Supply Method) followed by a material flow analysis (with certain assumptions) to arrive at a reasonable degree of waste material flow in and their subsequent transformation into waste.

A questionnaire survey can substantiate further, on the differentiated obsolescence rates. The present study considered such a possibility and based its model on an integrated approach of methodology.

Following section presents some case studies and review of works where different methods of E-Waste estimation are employed.

Statistics of generation of e-waste by different sectors in India:

The impact of e-wastes in India gave rise to several unsolved problems. Research has proven that 78% of computers have been installed in the sector of business.

Hence the concerned citizens are replacing the electronic products with renewable and nonrenewable items which are non-hazardous in nature.

This is the best idea to reduce the number of electronic wastes, and this is also recommended by the environmental specialists and the government officials. From the survey, it is found that due to outdated or old-fashioned products, a huge amount of 1.3 million personal computers only from the business fields and domestic sectors are discarded.

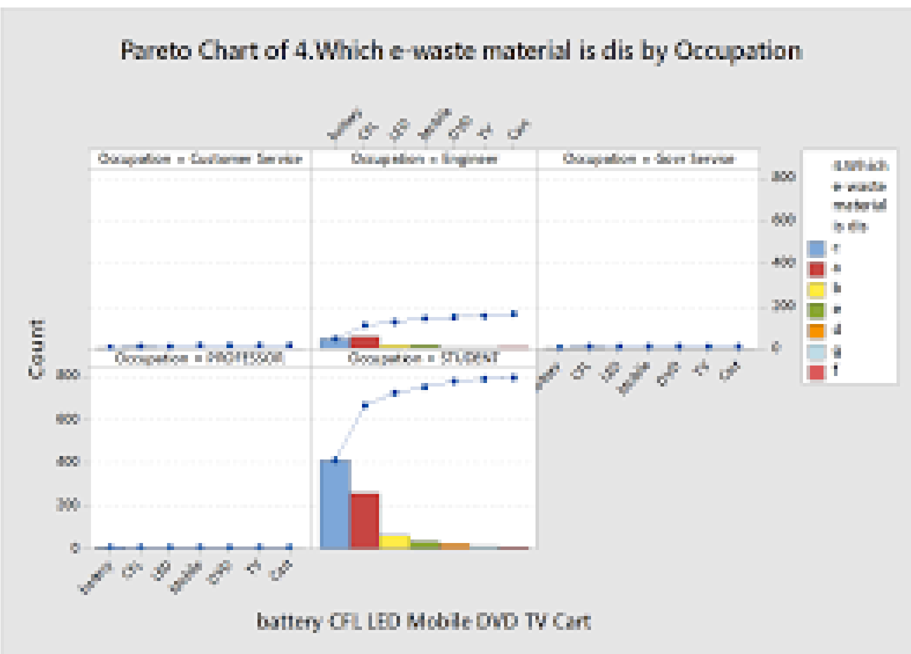
From the report by CII (Confederation of Indian Industry), it is found that 1.46 million tons of electronics create a huge amount of e-waste in India per year. 508 Uday Kumar. T

'The analysis shows that 86% of them get less than 100kgs of electronic & electrical waste which means for now, this is the scenario

FINDINGS

E-waste management in India and its standing:

Concerning environmental protection, there is a strict legislation by which there are rules and principles for e-wastes, especially for computer wastes. Detection of a high amount of certain substances in the waste materials confirm the hazardous nature of the e-waste, this is according to the 1989's Hazardous Waste Regulation. People who are responsible for the improper style of e-waste disposal and management are given punishments, and the law for these punishments is introduced by Central Pollution Control Board or CPCB. NGOs have represented a good strategy for waste management, administration of general awareness programs and distribution of advanced recycling machinery are also being carried out. The introduction of the technical guide by Department of Information technology (DIT) will as well lead to successful waste management.



Recovery and reuse:

In the recent scenario, the electronic waste recycling business is in all the areas of the developed countries. By properly disposing or reusing electronics, we can prevent health problems, reduce greenhouse gas emissions and create jobs. The recycling is done by sorting, dismantling, and recovery of valuable materials and this is achieved through refurbishing and reuse. The social and environmental benefits of reuse of electronics include diminished demand for new products. Recycling the printed circuit boards from the electronic wastes is one of the major challenges. The circuit board contains some of the precious metals such as silver, gold, platinum, etc. and base metals such as iron, copper, aluminum, etc. The best way to process e-waste is by melting circuit boards, burning the cable sheathing to recover copper wire and open-pit acid hang on for separating metals of value. In order to reclaim a waste material such as electrolysis, osmosis, electrolytic recovery, condensation, filtration, centrifugation, etc.

CONSUMER AWARENESS EFFORTS:

The prevention of e-waste is more preferred to any other waste management option and e-waste recycling. By donating the electronics for reuse, we extend the lives of valuable products and keep them out of the waste management system for a longer period of time. While donating the items, it should be confirmed that it is in good working condition.

This reuse process also benefits the society. By donating the electronics, the lower income families can be able to use electronics that they could not afford. The e-waste should be segregated at the site and sold or donated to various organizations; it should never be disposed with garbage and other household wastes.

While buying electronic products, preference should be made to those that:

- use recycled content
- are energy efficient
- are made with fewer toxic constituents

- utilize minimal packaging
- are designed for easy disassembly or upgrading

Discussion

PC and TV sales data for the study area and India as a whole was obtained from the industry association. Comparative time series growth of the installed base and yearly additions of PCs from 1996 to 2004 and for TVs from 1983 to 2005.

The market supply method was applied by assuming the average life of a PC to be 5 years and 7 years and the average life of a TV to be 10 years and 12 years. It was also assumed that 100% of electronic units sold in one particular year would become obsolete at the end of the average life. The amount of e-waste from PCs and TVs existing in the study area.

The average weight of a PC and a TV was taken as 27kg and 15kg, respectively. These weights have been estimated based on average weights of different products and brands available in the Indian market during the primary survey. E-waste based on the sales figures/penetration rate has been adjusted for externalities, i.e., the number of trucks carrying e-waste from outside and entering the study area per day, considering 365 days in a year, during which dismantling occurs on 300 working days.

Validation Qualitative and quantitative estimations were carried out with the identified stakeholders across the e-waste trade value chain. It was identified that two types of stakeholders, dismantlers and CRT runners, are involved in CRT handling.

The field survey results from the dismantler revealed that out of the total CRTs received for dismantling, the rerunning industry accepts 40%–45% of dismantled material; the remaining material is rejected. About 55%–60% of the rejected material goes for glass breaking.

Further, out of the total 40%–45% accepted material (CRTs) for processing, 10% is found to be intact and is sent for resale, whereas the remaining 90% is retuned. The total number of rerunning units operating in the study area is 15.

The daily output (retuned CRTs) per unit is 120–140 CRTs. Therefore, the total output per day from all units in the study area is 1800–2100 CRTs. This range of CRT output per day was used to validate the average life of a PC and a TV based on scenario analysis using the market supply method.

The number of CRTs being retuned every day was estimated using data. CRT fact sheets summarizing the results considering an average life of 7 years for a PC and 12 years for a TV

The total number of CRTs being retuned per day, calculated on the basis of an average life of 7 years for a PC and 12 years for a TV is 2050. This number is within the range obtained from the survey of the CRT industry.

Therefore, this market supply result validates the adopted approach. The total projected e-waste generation (TV and PC), calculated by using a power equation for the best fit of domestic market data in the study area based on the validated average life.

It is estimated that in 2010, e-waste generated from PCs and TVs in the study area will be more than 2 million units from the domestic market.

The Commission for Environmental Cooperation (CEC) is pleased to invite all interested persons to participate in a Workshop on E-waste Recycling and Refurbishing: Environmentally Sound Management Practices, to be held in Guadalajara, Mexico, 15–16 February 2011.

Aimed at small and medium-size businesses that recycle, refurbish or reuse electronic waste in North America, the event will foster the exchange of experiences among experts, regulatory officials from the governments of Canada, Mexico and the United States, and the public, to assess the environmental and economic challenges and benefits associated with the use and adoption of sustainable e-waste practices.

Experts and analysts will cover issues including managing hazardous substances, recovering precious metals, supporting green jobs and businesses, training, and improving the occupational health and safety of workers.

The sound management of e-waste is an issue of concern to NAFTA partners due to a rapidly growing number of electronic devices disposed of each year, compounded by a lack of infrastructure and comprehensive strategies to face this challenge.

Electronic devices—televisions, computers and cell phones among others—contain between 40 and 60 chemical elements, including precious and heavy metals, as well as persistent organic compounds and carcinogens that pose risks to human health and the environment if not treated appropriately.

By fostering the recycling and refurbishment of e-waste, the CEC also aims to help fight the illegal trade of these components in and from North America.

Participation at the event—open to the public—is free, but limited to the capacity of the meeting venue. To guarantee space, please complete the registration form no later than 10 February 2011.

You can also follow the workshop from anywhere in the world on the CEC website, where it will be webcast with simultaneous translation in Spanish, French and English.

The meeting agenda and registration form are available online at the meeting's webpage, with additional information to be added soon.

Conclusions

The market supply method can be easily applied to e-waste estimation in the Indian context, considering constraints in data collection as a result of the informal nature of the e-waste trade.

The application of this method is highly dependent on the estimation of the average life or obsolescence rate of an electronic item.

Since the average life is an indicator of consumer behavior, it includes elements of active usage, reuse, and storage of an electronic item before its recycling and final disposal.

Sensitivity analysis using different average life spans for an electronic item can factor elements of active usage, reuse, and storage into the assumption that 100% of electronic units sold in one particular year will become obsolete at the end of the average life.

Further, sensitivity analysis also factors in the dynamic nature of consumer behavior. This has been validated for PCs and TVs in the study area.

The higher rate of accumulation of waste products from the business sector and household appliances will be diminished by the Electronic waste policy.

Adequate laws by the local as well as the central government along with effective management strategies are the keys to an eco-friendly world.

Ultra-modern technologies should be developed with safety materials that can be manufactured to save the life of workers who work in recycling the e-wastes.

Labels that show the Eco-friendly items are a great thought and this should be implemented by all the manufacturers and also by the top-notch brands.

With the help of strict policies, strategies, awareness programs and high-tech machinery, the dream of India without wastes could be definitely achieved.

ITU has agreed to the fact that there is no unique or ideal model for e-waste management in developing countries, each of which is characterized by its own specific environmental, social, technological, economic and cultural conditions.

With a view to bridge the digital divide, there is exponential growth in the use of Electrical and electronic equipment (EEE) and so there is alarming effect on environment and human health when the ICT wastes are not disposed of scientifically. There is an emergent need to implement the existing policies and guidelines in line with the international standards and practices for a healthy e-waste management system.

Government policies should encourage the reuse of EEE aiming to minimize and recycle Waste Electrical and Electronic Equipment (WEEE). The Extended Producer Responsibility (EPR)do need to have clear regulations to mandate the ‘take back’ activity of companies strictly.

There is a clear need to have proper information system through standardized mechanisms. Eco-design can have a positive impact in reducing the rate of WEEE generation, facilitating the management of e- waste and recovery of materials, achieving cost reductions.

In Indian context, Ministry of Environment and Forests in the E-waste (Management & Handling- Rules, 2011) has clarified about the Reduction in the use of hazardous substances (RoHS) in the manufacture of electrical and electronic equipment where attempt is made to get ensured that new electrical and electronic equipment does not contain Lead, Mercury, Cadmium, Hexavalent Chromium, poly-brominated biphenyls (PBB) or poly-brominated diphenyl ethers (PBDE) which is to be achieved within a period of three years from the date of commencement of these rules.

Moe is also promoting the 3R Concept (Reduce, Reuse and Recycle) for Hazardous Waste Management has also defined the responsibilities of Central Pollution Control Board (CPCB)and State Pollution Control Board (SPCB) who are acting as monitoring authorities in respect of management of e-waste in India. Briefly the main functions of CPCB are:

- Coordination with State Pollution Control Boards
- Preparation of Guidelines for Environmentally Sound Management of e-waste
- Conduct assessment of e-waste generation and processing
- Recommend standards and specifications for processing and recycling e-waste
- Documentation & compilation of data on e-waste
- Conducting training & awareness program
- Enforcement of reduction in use of hazardous substances (RoHS)
- Incentives and certification for green design/products

The collection, storage, transportation, segregation, refurbishment, dismantling recycling and disposal of e-waste is also defined by the guidelines issued by the Central Pollution Control.

The DoT guidelines in the direction “to develop a robust and secure state-of-the-art telecommunication network providing seamless coverage with special focus on rural and remote areas for bridging the digital divide” have also specific regulations for the environmental and health issues arising from the telecom network.

The remuneration for adoption of green policy and incentive for use of renewable energy sources can be one practical and sustainable method for managing e-waste in Indian socio-cultural environment.

By promoting the use of energy efficient equipment and renewable energy technologies, and also adopting measures for reduction of carbon footprint, the concern for e-waste is also addressed in direction of long-term sustainability

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