Environ Monit Assess (2011) 172:249–262
DOI 10.1007/s10661-010-1331-9

E-waste scenario in India, its management and implications

Sushant B. Wath · P. S. Dutt · T. Chakrabarti

Received: 25 May 2009 / Accepted: 18 January 2010 / Published online: 12 February 2010

Abstract Electronic waste or E-waste comprises of old, end-of-life electronic appliances such as computers, laptops, TVs, DVD players, refrigerators, freezers, mobile phones, MP3 players, etc., which have been disposed of by their original users. E-waste contains many hazardous constituents that may negatively impact the environment and affect human health if not properly managed. Various organizations, bodies, and governments of many countries have adopted and/or developed the environmentally sound options and strategies for E-waste management to tackle the ever growing threat of E-waste to the environment and human health. This paper presents E-waste composition, categorization, Global and Indian E-waste scenarios, prospects of recoverable, recyclable, and hazardous materials found in the E-waste, Best Available Practices, recycling, and recovery processes followed, and their environmental and occupational hazards. Based on the discussion, various challenges for E-waste management particularly in India are delineated, and needed policy interventions were discussed.

S. B. Wath (✉) · P. S. Dutt · T. Chakrabarti
National Environmental Engineering Research Institute (NEERI), Nehru Marg, Nagpur, 440 020, Maharashtra, India
e-mail: sb_wath@neeri.res.in

Keywords E-waste management · Best available practices · Environmental and health impact · Developing countries

Introduction

E-waste and categorization

Electronics industry is the world's largest and fastest growing manufacturing industry. Rapid growth combined with rapid product obsolescence resulted in discarded electronics which is now the fastest growing waste stream in the industrialized world. The growing quantity of E-waste from electronic industry is beginning to reach disastrous proportions. Electronic Waste or E-waste is the term used to describe old, end-of-life electronic appliances such as computers, laptops, TVs, DVD players, refrigerators and freezers, mobile phones, MP3 players, etc. which have been disposed of by their original users. Thus, E-waste is generated out of relatively expensive and essentially durable products used for data processing, telecommunications, or entertainment in private households and businesses.

Technically, electronic waste is only a subset of Waste Electrical and Electronic Equipment (WEEE). According to the Organization for Economic Cooperation and Development (OECD), any appliance using an electric power supply that has reached its end-of-life would come under WEEE (EU 2002).

Composition of the E-waste is very diverse and complex. E-waste contains more than 1,000 substances, which can be classified as hazardous and nonhazardous substances. The electrical and electronic equipment can be broadly categorized into following categories (EU 2002):

1. Large household appliances (refrigerator, freezer, washing machine, cooking appliances, etc.)
2. Small household appliances (vacuum cleaners, watches, grinders, etc.)
3. IT and telecommunication equipment (PCs, printers, telephones, telephones, etc.)
4. Consumer equipment (TV, radio, video camera, amplifiers, etc.)
5. Lighting equipment (CFL, high intensity sodium lamp, etc.)
6. Electrical and electronic tools (drills, saws, sewing machine, etc.)
7. Toys, leisure, and sport equipment (computer/video games, electric trains, etc.)
8. Medical devices (with the exception of all implanted and infected products radiotherapy equipment, cardiology, dialysis, nuclear medicine, etc.)
9. Monitoring and control instruments (smoke detector, heating regulators, thermostat, etc.)
10. Automatic dispensers (for hot drinks, money, hot and cold bottles, etc.)

The waste electrical or electronic equipment include all components, sub-assemblies, and consumables, which are either a part or whole of such products at the time of discarding. The main materials found in electric and electronic waste are ferrous material (38%), non-ferrous material (28%), plastic (19%), glass (4%), other including wood, rubber, ceramic, etc. (11%).

Table 1 shows the average weight and composition of WEEE of selected electronic and electrical equipment commonly used in any household. The various items found in E-waste in different range make the E-waste more diverse and complex in nature (UNEP 2007). However, it shows that E-waste from these items can be dismantled into relatively small number of common components for further treatment. The materials found in the WEEE can be categorized as hazardous and non-hazardous materials. Table 2 shows the possible hazardous content in the component. The substances within the mentioned components, which cause most concern, are the heavy metals such as lead, mercury, cadmium, chromium (VI), halogenated substances (e.g., CFCs), polychlorinated biphenyls, plastics, and circuit boards that contain brominated flame retardants (BFRs). BFR can give rise to dioxins and furans during incineration. Other materials and substances that can be present are arsenic, asbestos, nickel, and copper. These substances may act as a catalyst to increase the formation of dioxins during incineration (DEFRA 2004).

Indian Scenario: E-waste scenario in India and its management

The problems associated with E-waste in India started surfacing after the first phase of economic liberalization, after 1990. Due to the stiff compe-

Table 1 Average weight and composition of WEEE of selected EEE commonly used

Appliances	Average weight (kg)	Iron (Fe) % weight	Non-Fe % metal weight	Glass % weight	Plastic % weight	Electronic component % weight	Others % weight
Refrigerators and freezers	48	64.4	6	1.4	13		15.1
Washing machine	40 to 47	59.8	4.6	2.6	1.5		31.5
PC	29.6	53.3	8.4	15	23.3	17.3	0.7
TV sets	36.2	5.3	5.4	62	22.9	0.9	3.5
Cellular phones	0.08 to 0.1	8	20	10.6	59.6		1.8

UNEP E-waste Assessment Manual Vol I (1) Data compiled from Waste from electrical and electronic equipment (WEEE)—quantities, dangerous substances and treatment methods, EEA Copenhagen (2003); (2) QWERTY and Eco-Efficiency analysis on cellular phone treatment in Sweden. TU the Netherland (2004)

Table 2 Possible hazardous substances in WEEE/E-waste components

Component	Possible hazardous content
Cooling	ODS
Plastic	Phthalate plasticize, BFR
Insulation	Insulation ODS in foam, asbestos, refractory ceramic fiber
Glass	Lead, Mercury (if coated)
CRT	Lead, Antimony, Mercury, Phosphors
LCD	Mercury
Rubber	Phthalate plasticizer, BFR
Wiring/Electrical	Phthalate plasticizer, Lead, BFR
Circuit board	Lead, Beryllium, Antimony, BFR
Fluorescent lamp	Mercury, Phosphorus, Flame Retardants
Thermostat	Mercury
BFR-containing plastic	BFRs
Batteries	Lead, Lithium, Cadmium, Mercury
CFC, HCFC, HFC, HC	Ozone depleting substances
External electric cables	BFRs, plasticizers
Electrolyte capacitors (over L/D 25 mm)	Glycol, other unknown substances

Compiled from WEEE and Hazardous Waste, A report produced for DEFRA (March 2004), AEA Technology

tition in the market of brand, quality, price, and services offered between the various Indian and Foreign companies, the electronic and consumer durable industry grew in India. Also, during the post-liberalization era, due to cheaper rate and increase in the purchasing capacity of the individuals, there was a big boom for the electronic goods industry in India, especially for the home appliances (TV, refrigerator, washing machine, AC, ovens, etc.), telecommunication, IT, and computers. Further, due to infrastructure reforms and e-governance, IT revolution in India is marked by the application of information technology in a big way in all areas. Figure 1 indicates the increase in the sales of PCs in last 8 years during 2001–2009 (MAIT 2008–2009).

According to TRAI, India added 113.26 million new cellular customers in 2008, with an average 9.5 million customers added every month. Cellular market grew from 168.11 million in 2003–2004 to 261.97 million in 2007–2008 (TRAI 2008–09). In 2006, microwave ovens and air conditioners registered a growth of about 25%. Refrigerator sales amounted to 4.2 millions in 2006–2007, and its production went up by 17% as compared to the preceding year. Washing machines, which have always seen poor growth, have seen reasonable growth in 2006. The penetration level of colored televisions (CTVs) is increased three times by 2007 (NCAER 2007).

These developments, along with indigenous technological advancement, have led to an addition of wide gamut of E-waste churned out from Indian households, commercial establishments, industries, and public sectors into the waste stream. Solid waste management, which is already a mammoth task in India, has become more complicated by the invasion of E-waste, particularly computer waste to India, from different parts of the world (IRGSSA 2007).

So far, the preliminary estimates suggest that total WEEE generation in India is approximately 1, 46,180 tonnes/year which is expected to exceed 800,000 tonnes by 2012. The top states, in order of highest contribution to WEEE, include Maharashtra, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, West Bengal, Delhi, Karnataka, Gujarat, Madhya Pradesh, and Punjab. The city-wise ranking of largest WEEE generators is Mumbai, Delhi,

Fig. 1 Total PC (Desktops and Notebooks) sales: 2001–2009

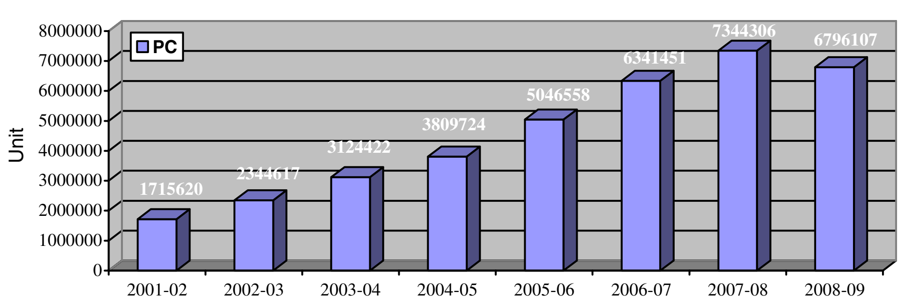

Table 3 Quantity of WEEE (Waste Electrical and Electronic Equipment) generated in Indian States

SN	States	WEEE (Tones)	SN	States	WEEE (Tonnes)
1	Andaman and Nicobar Islands	92.2	19	Lakshadweep	7.4
2	Andra Pradesh	12,780.3	20	Madhya Pradesh	7,800.6
3	Arunachal Pradesh	131.7	21	Maharashtra	20,270.6
4	Assam	2,176.7	22	Manipur	231.7
5	Bihar	3,055.6	23	Meghalaya	211.6
6	Chandigarh	359.7	24	Mizoram	79.6
7	Chhattisgarh	2,149.9	25	Nagaland	145.1
8	Dadra and Nagar Haveli	29.4	26	Orissa	2,937.8
9	Daman and Diu	40.8	27	Puducherry	284.2
10	Delhi	9,729.2	28	Punjab	6,958.5
11	Goa	427.4	29	Rajasthan	6,326.9
12	Gujarat	8,994.3	30	Sikkim	78.1
13	Haryana	4,506.9	31	Tamil Nadu	13,486.2
14	Himachal Pradesh	1,595.1	32	Tripura	378.3
15	Jammu and Kashmir	1,521.5	33	Uttar Pradesh	10,381.1
16	Jharkhand	2,021.6	34	Uttarakhand	1,641.1
17	Karnataka	9,118.7	35	West Bengal	10,059.4
18	Kerala	6,171.8		Total	146,180.7

Country Level WEEE assessment study by IRGSSA (2005)

Bangalore, Chennai, Kolkata, Ahmadabad, Hyderabad, Pune, Surat, and Nagpur. Table 3 shows quantity of WEEE generation in different states in India (IRGSSA 2005).

Present E-waste management system in India

Most of the activities right from the collection, transportation, segregation, dismantling, etc., are done by unorganized sectors manually. Being a rich source of reusable and precious material, E-waste is also a good source of revenue generation for many people in India. The big portion (rag pickers) of the Indian population earned their livelihood by collecting and selling the inorganic waste-like plastics, polythene bags, glass bottles, cardboards, paper, other ferrous metals, etc. Figure 2 shows the road map/trade chain of Electronic and Electrical Equipment's journey from manufacture/ importer to recycler/disposer found in most of the Indian cities (MPCB 2007).

In India, most of the operations related to E-waste such as collections, segregation, dismantling, recycling, and disposals are performed manually. In absence of the adequate technologies and equipment, most of the techniques used for the recycling/treatments of E-waste are very raw and dangerous (MPCB 2007). Improper recycling and disposal operations found in different cities of India often involve the open burning of plastic waste, exposure to toxic solders, dumping of acids, and widespread general dumping. As a result, pollutants are dumped into the land, air, and water, which are the cause of serious environmental problems in India. Also, the labors and workers employed in the dismantling and recycling units are poorly literate and uneducated, lacking the basic knowledge about the serious occupational and health risks associated with the operations. Most of the time, dismantling and recycling operations are performed by the workers without proper Personnel Protection Equipment. Mostly hammers, chisels, hand drills, cutters, electric torch/burners, and some time electric drills were used for dismantling the WEEE (MPCB 2007). These operations are carried out in very congested places in the center of cities and slums. Mostly, the dismantling and recycling areas are without any proper lighting and ventilation. In absence of suitable techniques and infrastructure, the workers and laborers working in such areas are prone to serious occupational health hazards (Empa 2004) Thus, there is no organized or formal E-waste management system in India.

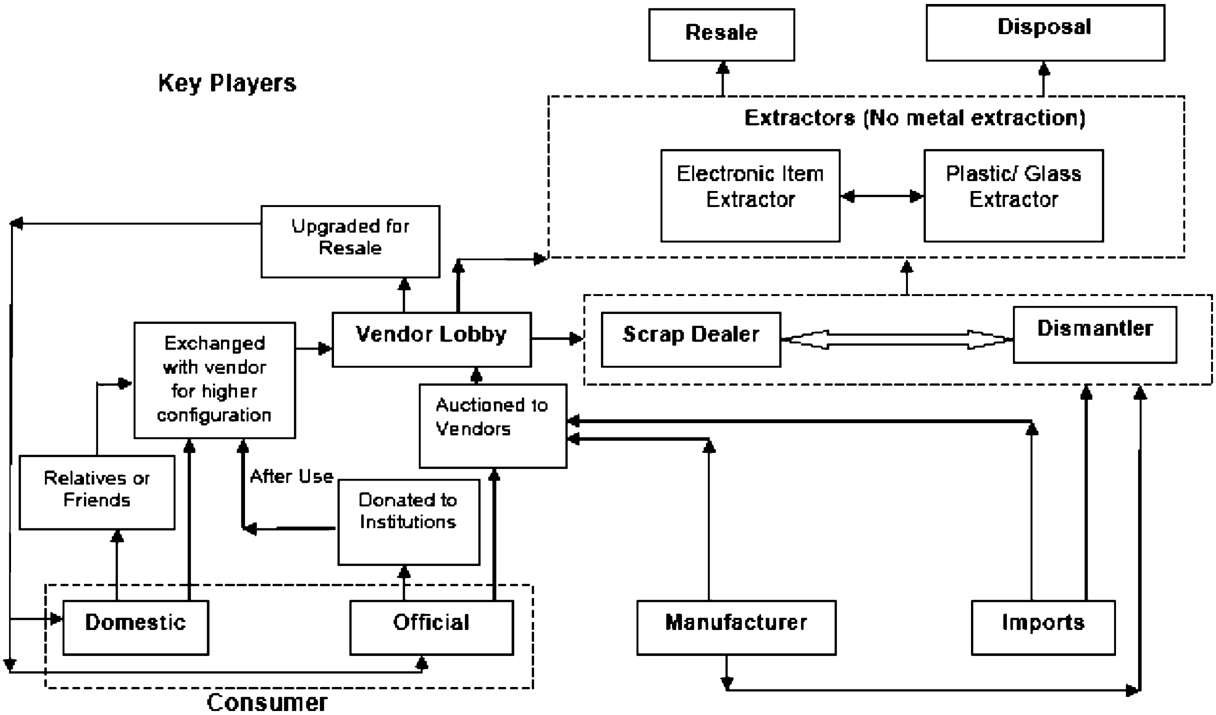

Fig. 2 Flow chart of E-waste trade cycle in India

Global scenario of E-waste management

Internationally, various legal frameworks have been enacted and enforced to regulate E-waste. The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and its Disposal plays a significant role in curbing the E-waste trade from OECD countries to Non-OECD countries. The EU has taken a lead to protect the environment from hazards of E-waste in Europe by framing two important directives, WEEE directive and Restriction of Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment Regulations directives. Many countries have implemented WEEE Directives (2002/96/EC) with detailed guidelines to assist the producers and consumers in understanding their duty to handle E-waste in environmentally sound manner (EU 2003):

- UK: Waste Electrical and Electronic Equipment, as derived from the WEEE directive, an EU directive, transcribed into UK legislation after being passed by Parliament in 2007. The legislation has put the responsibility of the reporting, financing, and treatment compliance obligations on the operators (private sector) of the producer compliance schemes, instead on each individual producer. Also, the operator is responsible for registering its members with the appropriate national regulator and for providing the details of equipment produced by the members. The producers, preprocessors, and exporters need to get registered with the producer compliance scheme by paying the fee, which can be used as an operational cost for running the scheme. The national regulator fixes the household WEEE quota for each producer compliance scheme. And the operator has to ensure that the WEEE allotted must be treated using best available treatment, recovery, and recycling techniques (Turner and Callaghan 2007).
- USA: US Environmental Protection Agency has initiated a green National Electronics Action Plan (NEAP) to address environmental concerns of electronics. The scope of NEAP is restricted to computers, televisions, and

cell phones. However, USA have not ratified the Basel Convention. Also, there is no federal legislation in place prohibiting or regulating E-waste generation, disposal, and export. Meanwhile, in the last couple of years, many states in USA have taken efforts for collection and recycling of E-waste from residential and commercial consumers in environmental friendly manner. Fifteen states have introduced the producer responsibility bills. The state of California has introduced a law for collecting the Advance Recycling Fee (ARF) from the consumer at the time of purchase of new product. The system charges ARF ranging from US $6 to US $10 for electronic items like TVs, laptops, and monitors (Gregory and Kirchain 2007).

Many countries have formulated their own legal instruments for restricting and regulating the hazards of electronic waste.

- People's Republic of China: In China, the electronic waste is regulated by the Administration of Control of Pollution caused by electronic information products (February 2006). Accordingly, the designer and manufactures of electronic information products are required to design and manufacture electronic information products in accordance with the national industrial standards. The administration also provides for penalty for imports, sellers, manufactures, and designer in case of noncompliance. The administration also has provision for penalty on importers, sellers, manufactures, and designer in case of noncompliance of the laid-down standards (Hicks et al. 2005). Table 4 gives the overview of China's national WEEE management-related legislation.
- India: In India, Ministry of Environment and Forests (MoEF) is the national authority responsible for legislation regarding waste management and environmental protection. Although MoEF has approved vide letter no. 23–23/2007-HSDM dated March 12, 2008, the guidelines for environmentally sound management of E-waste with an objective to provide guidance for identification of various sources of waste electrical and electronic equipment

Table 4 WEEE laws and regulation in China

Laws or regulations	Major content	Status/date
Law on the prevention of environmental pollution from solid waste (SEPA).	Disposal of municipal and industrial solid waste; use of solid wastes as raw materials	Effective from April 1, 1996.
Notification on the import of the seventh category of wastes (SEPA).	Ban on the import of the seventh category of waste.	Effective from February 1, 2000.
Notice on strengthening the environmental management of WEEE (SEPA).	WEEE processing to meet the requirements of the "Law on the prevention of environmental pollution from solid waste"; generation of WEEE to be reported to local EPBs.	Issued August 26, 2003.
Ordinance on the management of waste household electrical and electronic products recycling and disposal (Draft, NDRC).	Mandatory recycling of WEEE, based on extended producer responsibility; certification for 2nd hand appliances, and recycling enterprises.	Submitted for approval to the State Council in early 2005.
Management measure for the prevention of pollution from electronic products (Draft, MII).	Restrictions on the use of hazardous substances; 'green' product design; provision of information on the components, hazardous substances, and recycling.	If approved, effective from July 1, 2005; restrictions to be enforced after July 1, 2006.

BAN (2002); Guo et al. (2005, Draft); NDRC (2004, Draft); SEPA (1995, 2000, 2004, 2005); Chen (2004)

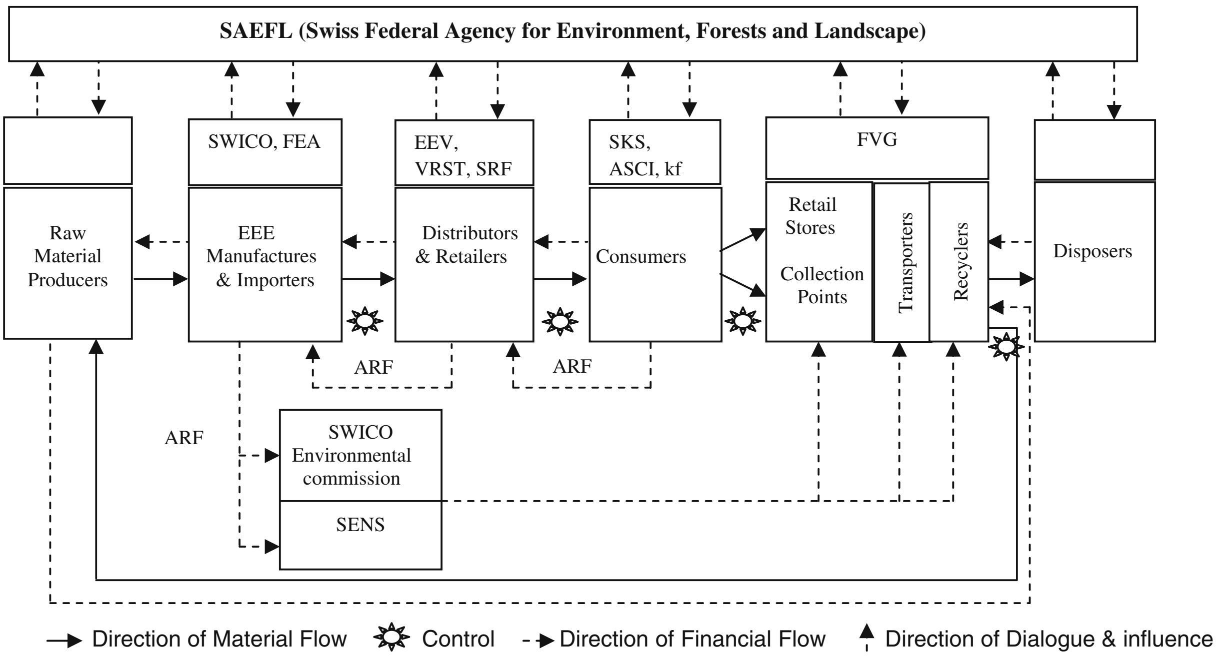

Fig. 3 ARF approach for E-waste management

and prescribed procedures for handling E-waste in an environmentally sound manner," (MoEF 2008). But there is no law or regulation specifically addressing the E-waste problem (MoEF 2008); however, most of the hazardous material found in the E-waste are covered under purview of "The Hazardous and Waste Management Rules, 2008" under the category of "hazardous" and "nonhazardous" waste.

Management of E-waste is a formidable task and involves multidisciplinary approach. The various management methodologies reported in the available literature include segregation, recycle, and recovery options and combinations thereof. However, there is no standard or proven methodology evolved as yet for the management of E-waste. In this context, the best available prac-

Table 5 Recoverable quantity of elements in a TV

Elements	%	PPM	Recoverable Wt. of element (Kg)
Aluminum	1.2		0.4344
Copper	3.4		1.2308
Lead	0.2		0.0724
Zinc	0.3		0.1086
Nickel	0.038		0.013756
Iron	12		4.344
Plastic	26		9.412
Glass	53		19.186
Silver		20	0.000724
Gold		10	0.000362

Compiled from data presented in Cui (2005)

Table 6 Recoverable Quantity of Elements in a PC

Material type	% Recovered
CFCs	0.20
Oil	0.32
Ferrous metals	46.61
Non-Ferrous metals	4.97
Plastics	13.84
Compressors	23.80
Cables/Plugs	0.55
Spent PurFoam	7.60
Glass	0.81
Mixed waste	1.30
Total	100.00
Materials disposed of to incinerator	0.20
Materials disposed of to landfill	8.90
Materials sent for recovery	90.90

Compiled from data presented in (1) Exporting Harm—High-Tech Trashing of Asia. Basel Action Network and Silicon Valley Toxics Coalition, US, 2005; (2) Management of Waste Electrical and Electronic Equipment, ACRR (2003) tices of management of E-waste have also been reviewed.

Best Available Practices (BAP)

- The Extended Producer Responsibility (EPR) is an environment protection strategy that makes the producer responsible for the entire lifecycle of the product, especially for take back, recycle, and final disposal of the product. Thus, the producer's responsibility is extended to the post-consumer stage of the product life cycle. This needs to be included in the legislative framework making EPR a mandatory activity associated with the production of electronic and electrical equipment over a period of time (OECD 2001).
- Switzerland is the first country in the world to have established a formal E-waste management system. The existing E-waste management system based on the ARF approach is given in Fig. 3. The effective collection of E-waste in Switzerland is primarily due to the efficient management of the E-waste stream by two producer responsibility organizations—The Swiss Association for Information, Communication and Organization

Table 7 Materials recovered from refrigerators

Elements	Content (% of total wt.)	Content (g)	Recycling eff. (%)	Recoverable wt. of element (g)
Plastics	23	6250	20	1,250.69408
Lead	6	1710	5	85.66368
Aluminum	14	3850	80	3,083.89248
Germanium	0.0016	0	0	0
Gallium	0.0013	0	0	0
Iron	20	5570	80	4,454.53312
Tin	1	270	70	191.88512
Copper	7	1880	90	1,696.14576
Barium	0.0315	10	0	0
Nickel	0.8503	230	0	0
Zinc	2	600	60	359.79072
Tanialum	0.0157	0	0	0
Indium	0.0016	0	60	0.26112
Vanadium	0.0002	0	0	0
Terbium	0	0	v0	0
Beryllium	0.0157	0	0	0
Gold	0.0016	0	99	0.430848
Europium	0.0002	0	0	0
Tritium	0.0157	0	0	0
Ruthenium	0.0016	0	80	0.34816
Cobalt	0.0157	0	85	3.62984
Palladium	0.0003	0	95	0.07752
Manganese	0.0315	10	0	0
Silver	0.0189	10	98	5.037984
Antinomy	0.0094	0	0	0
Bismuth	0.0063	0	0	0
Chromium	0.0063	0	0	0
Cadmium	0.0094	0	0	0
Selenium	0.0016	0	70	0.30464
Niobium	0.0002	0	0	0
Yttrium	0.0002	0	0	0
Rhodium	0	0	50	0
Mercury	0.0022	0	0	0
Arsenic	0.0013	0	0	0
Silica	24.8803	6770	0	0

Compiled from data presented in "Waste Electrical and Electronic Equipment (WEEE), Pilot Scheme Report, Producer Responsibility Unit Environment and Heritage Service, Government of UK 2005

Technology and Stiftung Entsorgung Schweiz (Khetriwal et al. 2005).

- RoHS in the Electronic and Electrical Equipment: There is an increasing trend in the reduction in the use of hazardous substances such as lead, cadmium, mercury, polychlorinated biphenyls, and other toxic and hazardous substances for which safe substitutes have been found. Many countries have adopted the RoHS regulations in the manufacture of electrical and electronic equipment (EU 2002).

E-waste management: implications

Prospects of E-waste recycling and recovery towards the concept of urban mining

Although there is large amount of E-waste generation in India, there is no systematized or formal system available for handling the E-waste in a scientifically as well as environmental-friendly manner. Large amount of E-waste is being treated and dumped as a municipal solid waste only. E-waste, being rich in ferrous materials, nonferrous materials, plastic, and precious materials, has turned out as a major business opportunity for many. In the E-waste recycling, mostly manual dismantling is practiced. A variety of tools is involved in the dismantling process for removing the hazardous components and recovery of reusable or valuable components and materials. Mainly the mechanical/ physical recycling process practiced involved screening, shape separation, magnetic separation, electric conductivity-based separation, density-based separation, etc.; techniques depending upon the quantity, type, size, and shape of the material and component in E-waste. Tables 5, 6, and 7 show the recoverable quantity of elements in various WEEE.

Treatment and processing options for E-waste

A versatile E-waste management technology package involving recovery of valuable metals, minimizing environmental and health impacts with demonstration on viable scale needs to be developed.

Mainly the treatment of E-waste is done at three levels. The output of the first is input to the second stage. Environmentally sound E-waste treatment technologies are used at three levels as described below:

1. 1st level treatment
2. 2nd level treatment
3. 3rd level treatment

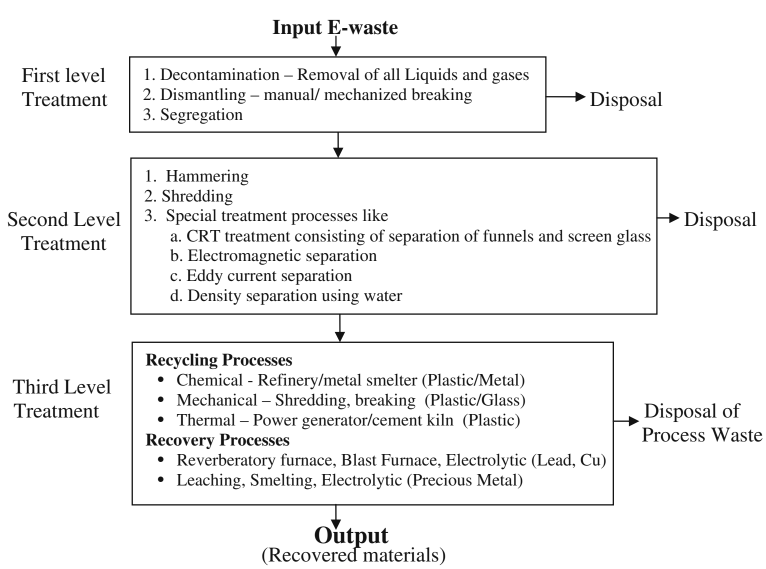

Fig. 4 Three tire treatment processes for recovery/recycling E-waste

Table 8 Occupational and environmental hazards associated with E-waste processing

Computer/E-waste components	Processes used	Potential occupational hazard	Potential environmental hazard
Cathode ray tubes (CRT)	Regunning, breaking, removal of yoke and dumping	Silicosis Cuts from CRT glass in case of implosion Inhalation or contact with phosphor containing cadmium or other metals Glass Dust inhaling	Lead, barium, and other heavy metals leaching into ground water, release of toxic phosphor
Printed circuit board (PCB)	De-soldering and removing computer chips	Tin and lead inhalation Possible brominated dioxin, beryllium cadmium and mercury inhalation	Air emission of same substances
Printed circuit board processing	Open burning and acid bath of waste boards that had chips removed to remove final metals	Toxicity to workers and nearby residents from tin, lead, brominated dioxin, beryllium cadmium and mercury inhalation Respiratory irritation Acid contact with eyes, skin may result in permanent injury	Hydrocarbons, heavy metals, brominated substances, etc., discharged directly into river and banks Acidifies the river destroying fish and flora.
Printed circuit board processing	Open burning and acid bath of waste boards that had chips removed to remove final metals	Inhalation of mists and fumes of acids, chlorine and sulfur dioxide gases can cause respiratory irritation to severe effects including pulmonary ederm, circulatory failure and death	Tin lead and contamination of immediate environment including surface and groundwater Brominated dioxins, beryllium cadmium and mercury emissions
Chips and other gold plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Toxicity to workers and nearby residents from tin, lead, brominated dioxin, beryllium cadmium and mercury inhalation	Hydrocarbons, heavy metals, brominated substances, etc., discharged directly into river and banks

		Respiratory irritation Acid contact with eyes, skin may result in permanent injury Inhalation of mists and fumes of acids, chlorine and sulfur dioxide gases can cause respiratory irritation to severe effects including pulmonary ederm, circulatory failure, and death	Acidifies the river destroying fish and flora Tin lead and contamination of immediate environment including surface and groundwater Brominated dioxins, beryllium cadmium and mercury emissions
Plastics from computer and peripherals e.g. printers, keyboards, monitors etc.	Shredding and low temperature melting to be reutilized in low grade plastics	Probable Hydrocarbons, heavy metals, brominated dioxins exposure	Emissions of brominated dioxins and heavy metals and hydrocarbons
Computer wires	Open burning and stripping to remove copper	Brominated and chlorinated dioxins, polycyclic aromatic hydrocarbons (PAH) (carcinogenic) exposure to workers living in the burning works area Cuts from knife in case of implosion	Hydrocarbons ashes including PAH's discharged to air, water and soil
Miscellaneous computer parts encased in rubber or plastic e.g. steel rollers	Open burning recover steel other metals	PAH (carcinogenic) and potential dioxin exposure	Hydrocarbons ashes including PAH's discharged to air, water and soil
Toner Cartridges	Use of paintbrushes to recover toner without any precaution	Respiratory tract irritation Carbon black possible human carcinogen Cyan, yellow, and magenta toners unknown toxicity	Cyan, yellow and magenta toners unknown toxicity
Secondary steel or copper and precious metal smelting	Furnace recovers steel or copper from waste including organics	Exposure to dioxins and heavy metals	Emissions of heavy metals

Puckett et al. (2002) (http://ban.org/E-waste/technotrashfinalcomp.pdf (Feb. 2002)

All the three levels of E-waste treatment are based on the material flow. The material flows from 1st level to 3rd level treatment. Figure 4 shows the three level treatments. Each level treatment consists of unit operations where E-waste is treated, and output of 1st level treatment serves as input to the next level treatment. After the 3rd level treatment, the residues are disposed of either in hazardous waste Treatment Storage and Disposal Facility (TSDF) or incinerated. The efficiency at 1st and 2nd levels determines the quantity of residues going to TSDF or incineration, while the 3rd level E-waste treatment is mostly carried out mainly to recover ferrous, nonferrous metals, plastics, and other items of economic value (Johri 2008).

Environmental and health implications

E-waste is a serious issue, and in absence of the globally acceptable E-waste definition, its related environmental and health hazards cannot be addressed in a global manner. In India, there is no law or regulation specifically addressed to the E-waste problem; however, most of the hazardous materials found in E-waste are cover under purview of "The Hazardous and Waste Management Rules, 2008" under the category of "hazardous" and "nonhazardous" waste. In most of the Indian cities, E-waste is treated as the municipal waste, and no special attention is given to the activities related to its collection, handling, dismantling, and recycling. Most of the activities related to the E-waste collection, handling, dismantling, and recycling are mainly being performed by the unorganized or informal sectors lacking the technical and infrastructural abilities and knowledge about the serious implications of the E-waste handling and disposal on environment and human health. The environmental impact and health risk associated with E-waste are of very critical and serious in nature leading to degradation and pollution of the natural resources and can lead to chronic diseases in human beings. Due to the hazards involved, disposing and recycling E-waste pose serious environmental and occupation implications. Table 8 lists its associated impacts.

Challenges and opportunities

Under the scenario, the E-waste management strategy for India has the following challenges, which need to be studied and addressed in more systematic and scientific manner:

Scientific challenges

- Eco-friendly recovery solutions
  - Precious metals
  - Base metals
- Value addition to recyclables for reuse
  - Plastics
  - Glass and other recyclables
- Disposal of process waste and residues
  - Size reduction
  - Toxic reduction

Engineering challenges

- Scientific collection, transport, handling, segregation, and disposal of E-waste
- Integrated/distributed processing facilities
  - Unorganized to organized
  - Involvement of SMEs and NGOs
- Feasible techno-economical solutions
  - Processing
  - Recycling
  - Recovery

Organizational challenges

- Appropriate definition for E-waste in Indian context
- Inventorization of E-waste generation, import, and its characterization
- Organization and structuring E-waste management system
- Training and awareness on safety, health, and environment

Further, the role and responsibility of the government is very important for developing the E-waste management strategy for India in terms of transboundary hazardous waste flow, effect of the government policies on employment, in both

E-waste recycle exporting and importing countries. And as global hazardous waste always flows to destinations with weaker environmental regulations or low economic development, the dirty side of its recycling process would never be properly addressed. The policy should be to design and find out the effective ways to improve job quality in the recycling industry in India, where low-skilled labor is abundant and people are desperate for any income. Any approach should maintain balance between environmental and occupational health along with the economic development.

Conclusion

The problem of E-waste is growing in alarming proportions in India as also in the world. Although many developed countries have established well-defined E-waste management systems, the systems in India have barriers from socioeconomic, infrastructural, and legal reasons. The E-waste recycling and recovery options practiced in India are very outdated and hazardous, causing severe environmental and occupational hazards. There is a fundamental difference between the current European models of E-waste management and the reality of E-waste recycling in India. There is a need to focus more on levels 2 and 3 treatment systems involving recycling and recovery options for better E-waste treatment and management. At the same time, new initiatives and best practices like ARF and EPR need to be introduced in the country.

Unlike the European E-waste system where consumers need to pay for the disposal of their E-waste or return them free of charge to recycler, consumers in India, however, expect to receive payment for their E-waste, which is viewed as a potentially valuable resource. Due to which, management of E-waste, if properly carried out, is an opportunity as it is often called as "urban mining." For the environmentally safe treatment and recycling of E-waste, the high initial investment is required for setting facility fitted with technologically advanced equipment and processes. The role of public–private partnership plays a key role in developing and organizing a sound E-waste management strategy in India. Although very few private enterprises have established the facilities for the E-waste treatment in few cities like Bangalore, Chennai, and Noida which are handling and treating the E-waste in more scientific and environmental-friendly manner, more such enterprises need to be established in other cities too.

There is a need for further research and consideration on policy as well as technical level to answer how to adopt and successfully combined the experience and know-how of the existing E-waste management models from abroad, with the current E-waste system in India, in order to have the formal and well-regulated E-waste Management system for India.

References

BAN (2002). *The Basel Action Network (BAN), the Silicon Valley Toxics Coalition (SVTC), Toxics Link India, SCOPE (Pakistan), Greenpeace China*. Exporting harm: The high-tech trashing of Asia. Seattle, WA, and San Jose, CA; February 25th 2002.

Chen, P. (2004). WEEE recycling and legislation development in China. In *Conference paper, Electronics Goes Green 2004*, 6–8 September, Berlin.

Cui, J. (2005). *Compiled from data presented in "Mechanical Recycling of Consumer Electronic Scrap. Licentiate Thesis 2005:36, Luleå University of Technology, Luleå, Sweden."* Cui.j.

DEFRA (2004). *Department for Environment, Food and Rural Affairs (DEFRA) Report*. March 2004 <www.defra.gov.uk>.

Empa (2004). *Federal Laboratories for Materials Testing and Research (Empa), E-waste pilot study Delhi: Knowledge partnerships with developing and transition countries*. St. Gallen: Empa (http://www.ewaste.ch/).

EU (2002). *European Union Waste Electronic Electrical Waste (WEEE) Directive*. Brussels: EU.

EU (2003). *European Union Waste Electrical and Electronic Equipment (WEEE) Directive*. Brussels: EU.

Gregory, J., & Kirchain, A. (2007). A comparison of North American electronic recycling systems. In *Proceedings of the 2007 IEEE international symposium on electronics and the environment* (pp. 227–232). IEEE.

Guo, D., Wu, Y., Yu, H., & Ge, W. (Eds.) (2005). *The impact of EU environmental requirements on China (Draft)*. State Environmental Protection Administration, Policy Research Centre for Environment and Economy and Deutsche gesellschaft fur technische zusammenarbeit (GTZ) GmbH.

Hicks, C., Dietmar, R., & Eugster, M. (2005). The recycling and disposal of electrical and electronic waste in China- legislative and market responses.

Journal of Environmental Impact Assessment Review, 25, 459–471. http://www.sepa.gov.cn/eic/649086798147878912/20031017/1042127.shtml [access date: April 12, 2005].

IRGSSA (2005). *Country Level WEEE Assessment study by IRG Systems South Asia Pvt. Ltd*. New Delhi: IRGSSA (www.irgssa.com).

Johri, R. (Ed.) (2008). *E-waste management, implications, regulations and management in India and current global best practices*. New Delhi: Teri.

Khetriwal, D. S., Kraeuchi, P., & Schwaninger, M. (2005). A comparison of electronic waste recycling in Switzerland and in India. *Journal of Environmental Impact Assessment Review, 25*, 492–504.

MAIT (2008–2009). *Manufacturer's Association for Information Technology Industry performance*. Annual Review 2008–09 <http://www.mait.com>.

MoEF (2008). *Guidelines for Environmentally Sound Management of E-WASTE*. (As approved vide Ministry of Environment and Forestry (MoEF) letter No. 23–23/2007-HSMD dated March 12, 2008).

MPCB (2007). *Report on Assessment of Electronic Wastes in Mumbai-Pune Area* (MPCB report- March, 2007).

NCAER (2007). *National Council of Applied Economic Research*. India <www.ncaer.org>.

NDRC (2004). *P.R.C. National Development and Reform Commission (NDRC)*. Ordinance on the management of waste household electrical and electronic products recycling and disposal (Draft). NDRC Express, September 19, 2004.

OECD (2001). *Extended producer responsibility; a guidance manual for governments*. Paris: Organization of Economic Co-operation and Development (OECD).

Puckett, J., Byster, L., Westervelt, S., Gutierrez, R., Davis, S., Hussain, A., et al. (2002). *A report exporting harm*. The High-Tech Trashing of Asia February 25, 2002. http://ban.org/E-waste/technotrashfinalcomp.pdf.

SEPA (1995). *P.R.C. State Environmental Protection Administration, Law on the prevention of environmental pollution from solid waste*. PRC Presidential Order, No. 58, October 30, 1995.

SEPA (2000). *P.R.C. State Environmental Protection Agency. Notification on the import of the seventh category of wastes*. SEPA Document 19/2000, 2000.

SEPA (2004). *P.R.C. State Environmental Protection Administration. Notice on the environmental management situation of waste electric and electronic products*. http://www.crra.com.cn/hykx(36).htm [access date: October 25th, 2004].

SEPA (2005). *P.R.C. State Environmental Protection Agency, Notice on strengthening the Environmental management of WEEE*; 2003.

TRAI (2008–09). *Telecom Regulatory Authority of India*. Annual Report 2008–09 <www.trai.gov.in>.

Turner, M., & Callaghan, D. (2007). Waste electrical and electronic equipment directive, UK to finally implement the WEE directive. *Computer Law and Security Report, 23*, 73–76.

UNEP (2007). *United Nations Environment Programme: E-waste Assessment Manual*.