Environmental Problems and Current Management of E-waste

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Abstract

In this paper the environmental problems related with the discarded electronic appliances, known as e-waste, are reviewed. Moreover, the current and the future production of e-waste, the potential environmental problems associated with their disposal and management practices are discussed whereas the existing e-waste management schemes in other countries are also quoted.

Keywords: *e-waste management, environmental pollution, recycling.*

1. Introduction

Advances in the field of science and technology brought about industrial revolution in the 18th Century which marked a new era in human civilization. In the 20th Century, the information and communication revolution has brought enormous changes in the way we organize our lives, our economies, industries and institutions. These spectacular developments in modern times have undoubtedly enhanced the quality of our lives. At the same time, these have led to manifold problems including the problem of massive amount of hazardous waste and other wastes generated from electric products. These hazardous and other wastes pose a great threat to the human health and environment. The issue of proper management of wastes, therefore, is critical to the protection of livelihood, health and environment. It constitutes a serious challenge to the modern societies and requires coordinated efforts to address it for achieving sustainable development.

According to the Basel Convention, wastes are substances or objects, which are disposed of or are intended to be disposed of, or are required to be disposed of by the provisions of national laws [1]. Additionally, wastes are such items which people are required to discard, for example by law because of their hazardous properties. Our daily activities give rise to a large variety of different wastes arising from different sources. Thus, municipal waste is waste generated by households and consists of paper, organic waste, metals, etc. The wastes generated by production processes, households and commercial activities are hazardous waste. Biomedical waste is waste generated by hospitals and other health providers and consists of discarded drugs, waste sharps, microbiology and biotechnology waste, human anatomical waste, animal waste, etc. Radioactive waste is any material that contains a concentration of radionuclides greater than those deemed safe by national authorities, and for which, no use is foreseen. Other sources of waste include end-of-life vehicles, packaging waste, tyres, agricultural waste, etc [2]. These waste substances are in the long

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run hazardous in nature as they are ignitable, corrosive, reactive, toxic, explosive, poisonous or infectious. Hence, they pose substantial or potential threat to public health and the environment.

Like hazardous waste, the problem of e-waste has become an immediate and long term concern as its unregulated accumulation and recycling can lead to major environmental problems endangering human health. The information technology has revolutionized the way we live, work and communicate bringing countless benefits and wealth to all its users. The creation of innovative and new technologies and the globalization of the economy have made a whole range of products available and affordable to the people changing their lifestyles significantly. New electronic products have become an integral part of our daily lives providing us with more comfort, security, easy and faster acquisition and exchange of information. But on the other hand, it has also led to unrestrained resource consumption and an alarming waste generation. Both developed countries and developing countries like India face the problem of e-waste management. The rapid growth of technology, up gradation of technical innovations and a high rate of obsolescence in the electronics industry have led to one of the fastest growing waste streams in the world which consist of end of life electrical and electronic equipment products. It comprises a whole range of electrical and electronic items such as refrigerators, washing machines, computers and printers, televisions, mobiles, i-pods, etc., many of which contain toxic materials. Many of the trends in consumption and production processes are unsustainable and pose serious challenge to environment and human health. Optimal and efficient use of natural resources, minimization of waste, development of cleaner products and environmentally sustainable recycling and disposal of waste are some of the issues which need to be addressed by all concerned while ensuring the economic growth and enhancing the quality of life. The countries of the European Union (EU) and other developed countries to an extent have addressed the issue of e-waste by taking policy initiatives and by adopting scientific methods of recycling and disposal of such waste. The EU defines this new waste stream as 'Waste Electrical and Electronic Equipment' (WEEE). As per its directive, the main features of the WEEE include definition of 'EEE', its classification into 10 categories and its extent as per voltage rating of 1000 volts for alternating current and 1500 volts for direct current. The EEE has been further classified into 'components', 'sub-assemblies' and 'consumables'[3]. Since there is no definition of the WEEE in the environmental regulations in India, it is simply called 'e-waste'. E-waste or electronic waste, therefore, broadly describes loosely discarded, surplus, obsolete, broken, electrical or electronic devices [4].

1.1. Composition of E-waste

E-waste consists of all waste from electronic and electrical appliances which have reached their end- of- life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal. It includes computer and its accessories monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other household appliances [5]. The composition of e-waste is diverse and falls under 'hazardous' and 'non-hazardous' categories. Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber and other items. Iron and steel constitute about 50% of the waste, followed by plastics (21%), non-ferrous metals (13%) and other constituents. Non-ferrous metals consist of metals like copper, aluminium

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and precious metals like silver, gold, platinum, palladium and so on [6]. The presence of elements like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants beyond threshold quantities make e-waste hazardous in nature. It contains over 1000 different substances, many of which are toxic, and creates serious pollution upon disposal [7]. Obsolete computers pose the most significant environmental and health hazard among the e-wastes.

2. Amount of electrical waste world-wide

The global e-waste production is assessed at 20-50 Mt/year [8], equal to 1-3% of the estimated global urban waste production (1636 Mt) [9-10]. PCs, cell phones and TVs will contribute 5.5 Mt in 2010 and will amount to 9.8 Mt in 2015. In wealthier countries, e-waste will stand for 8% of the urban waste volume [11]. Each electronic item's participation in the annual e-waste production, E (kg/year), depends on each electronic item's mass, M (kg), its quantity (number) in the market and consumption, N, and its average life cycle, L (year).

$$E = MN/L \qquad (1)$$

Electronic computers with an average 3-year life cycle [12] contribute to a greater extent to the total e-waste flow compared to refrigerators and electrical cook-stoves, having an average life cycle of 10-12 years. Certain e-waste types along with their mass and estimated life cycle are summarized in Table 1.

Table 1. E-waste types and their estimated life cycle.

Item	Mass of Item (kg)	Estimated life (years)
Personal Computer (PC)	25	3
Fax machine	3	5
High-fidelity system	10	10
Cell phone	0.1	2
Electronic games	3	5
Photocopier	60	8
Radio	2	10
Television	30	5
Video recorder/DVD Player	5	5
Air-conditioner	55	12
Dish washer	50	10
Electric cooker	60	10
Food mixer	1	5
Freezer	35	10
Hair-dryer	1	10
Iron	1	10
Kettle	1	3
Microwave	15	7
Refrigerator	35	10
Telephone	1	5
Toaster	1	5
Tumble Dryer	35	10
Vacuum cleaner	10	10
Washing machine	65	8

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 out-dated (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 Phonebloks. 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 [13]. An estimated 50 million tons of E-waste are produced each year [14]. 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.[8][9]

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 [15]. The United States is the world leader in producing electronic waste, tossing away about 3 million tons each year.[11] 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 [16].

Society today revolves around technology and by the constant need for the newest and most high tech products we are contributing to mass amount of e-waste [17]. 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 [13]. As of 2013, Apple has sold over 796 million iDevices (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 life spans because they know that the consumer will want a new product and will buy it if they make it.[14] In the United States, an estimated 70% of heavy metals in landfills come from discarded electronics [15-16].

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 [17].

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3. Impact of hazardous substances on health and environment

The processes of dismantling and disposing of electronic waste in developing countries lead 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 [9].

One study of environmental effects in Guiyu, China found the following [11]:

- 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

Table-2: 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.

The different substances-elements-pollutants related to e-waste are presented in Table 4. Some of them, such as heavy metals, are used in the production of electronic items, while others, such as Polycyclic Aromatic Hydrocarbons (PAHs) are produced by e-waste burning at low temperature. Burning the isolating plastic cover of cables in open barrels produces 100 times more dioxins than domestic waste burning [13-14]. Considering that the annual e-waste production approximates 20Mt, the total quantities of the several pollutants contained in the e-waste flow result, to a great extent, in landfills or recycling centres affecting the environment and/or public health. Therefore, despite significant recycling, e-waste is liable for 5000 t Cu annually released to the environment [9, 13-14]. PBDEs (Polybrominated biphenyl ethers) are combustion retardants that finally result in the environment and, given that they are lipophilic compounds, are bioaccumulated in living organisms [14], while the refrigerators and air-conditioners discarded contain CFCs (Chlorofluorocarbons) that will eventually destroy the ozone layer.

The waste from electronic products include toxic substances such as cadmium and lead in the circuit boards; lead oxide and cadmium in monitor cathode ray tubes (CRTs); mercury in switches and flat screen monitors; cadmium in computer batteries; polychlorinated biphenyls in older capacitors and transformers; and brominated flame retardants on printed circuit boards, plastic casings, cables and PVC cable insulation that releases highly toxic dioxins and furans when burned to retrieve copper from the wires.48 Many of these substances are toxic and carcinogenic. The materials are complex and have been found to be difficult to recycle in an environmentally sustainable manner even in developed countries. Listed in the table below are the harmful elements in the compositions of electrical and electronic appliances that can be hazardous to health and environment [3]:

Table-3

Metal	Danger
Lead	A neurotoxin that affects the kidneys and the reproductive system. High quantities can be fatal. It affects mental development in children. Mechanical breaking of CRTs (cathode ray tubes) and removing solder from microchips release lead as powder and fumes.
Plastics	Found in circuit boards, cabinets and cables, they contain carcinogens. BFRs or brominated flame retardants give out carcinogenic brominated dioxins and furans. Dioxins can harm reproductive and immune systems. Burning PVC, a component of plastics, also produces dioxins. BFR can leach into landfills. Even the dust on computer cabinets contains BFR.
Chromium	Used to protect metal housings and plates in a computer from corrosion. Inhaling hexavalent chromium or chromium 6 can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer.
Mercury	Affects the central nervous system, kidneys and immune system. It impairs foetus growth and harms infants through mother's milk. It is released while breaking and burning of circuit boards and switches. Mercury in water bodies can form methylated mercury through

	microbial activity. Methylated mercury is toxic and can enter the human food chain through aquatic.
Beryllium	Found in switch boards and printed circuit boards. It is carcinogenic and causes lung diseases.
Cadmium	A carcinogen. Long-term exposure causes Itai-itai disease, which causes severe pain in the joints and spine. It affects the kidneys and softens bones. Cadmium is released into the environment as powder while crushing and milling of plastics, CRTs and circuit boards. Cadmium may be released with dust, entering surface water and groundwater.
Acid	Sulphuric and hydrochloric acids are used to separate metals from circuit boards. Fumes contain chlorine and sulphur dioxide, which cause respiratory problems. They are corrosive to the eye and skin.

Other health effects

i. DNA breaks can increase the likelihood of developing cancer (if the damage is to a tumor suppressor gene)
ii. DNA damages are a special problem in non-dividing or slowly dividing cells, where unrepaired damages will tend to accumulate over time. On the other hand, in rapidly dividing cells, unrepaired DNA damages that do not kill the cell by blocking replication will tend to cause replication errors and thus mutation
iii. Elevated Reactive Oxygen Species (ROS) levels can cause damage to cell structures (oxidative stress)

Most electronic goods contain significant quantities of toxic metals and chemicals like mercury, which is currently being phased out in the developed countries. Mercury is mobile and poisonous in any form - inorganic, organic or elemental. Its organic compound methyl mercury has been scientifically proved to be a neuro-toxicant that damages the brain. It is geno-toxic too as it passes through the placental and the bloodbrain barrier, putting the foetus at risk. Mercury is known to cause severe and permanent damage to the central nervous system, lungs and kidneys. It can trigger depression and suicidal tendencies and cause paralysis, Alzheimer’s disease, speech and vision impairment, allergies, hypospermia and impotence. Mercury bio-accumulates (builds up in organisms) and biomagnifies (moves up the food chain). According to the United Nations Environment Programme’s (UNEP) Global Mercury Assessment Report, even minuscule increases in methyl mercury exposures can affect the cardiovascular system [8].

E-waste typically contains complex combinations of materials and components down to microscopic levels. The wastes are broken down in not just for recycling but for the recoverable materials such as plastic, iron, aluminium, copper and gold. However, since e-waste also contains significant concentration of substances that are hazardous to human health and the environment, even a small amount of e-waste entering the residual waste will introduce relatively high amount of heavy metals and halogenated substances. Such harmful substances leach into the surrounding soil, water and air during waste treatment or when they are dumped in landfills or left to lie around near it. Sooner or later they would adversely affect human health and ecology.

Unless suitable safety measures are taken, these toxic substances can critically affect the health of employees and others in the vicinity – who manually sort and treat the waste – by entering their body [6]

1. through respiratory tracts,
2. through the skin, or
3. through the mucous membrane of the mouth and the digestive tract.

Therefore, the health impact of e-waste is evident. There is no doubt that it has been linked to the growing incidence of several lethal or severely debilitating health conditions, including cancer, neurological and respiratory disorders, and birth defects. This impact is found to be worse in developing countries like India where people engaged in recycling e-waste are mostly in the unorganized sector, living in close proximity to dumps or landfills of untreated e-waste and working without any protection or safeguards. Many workers engaged in these recycling operations are the urban poor and unaware of the hazards associated with them. For instance, such recycling activities lead to the deterioration of local drinking water which can result in serious illnesses. It was found that a river water sample from the Lianjiang river near a Chinese "recycling village" had lead levels that were 2400 times higher than the World Health Organization Drinking Water Guidelines thereby involving a serious health hazard [9, 13-14].

4. E-waste management – Current situation

4.1. Greece

The average annual e-waste production in Greece for the period 2003-2006 came up to approximately 170 Kt, representing 3.8% of the total amount of domestic solid waste [18]. 90% of e-waste for the same period had been mixed with other urban solid waste or had been recycled with other materials (e.g. metal waste), with no prior process (a management practice mentioned as "grey recycling"). In order to deal both with the developing problem of "grey recycling" and the increasing amounts of e-waste, the operation of an authorized alternative e-waste management system started in 2004, having as main responsibilities the collection, transposition and process in special facilities. The system collected approximately 0.1 kilotons (Kt) in 2005, first year of operation, 31.5 Kt in 2007, 47 Kt in 2008 and 25 Kt in the first five months of 2009, overbalancing the national goal, as defined by the European and Greek legislation. These goals include the separate collection of at least 4 kg/resident/year of e-waste of domestic origin, that is 44 Kt/year for Greece in total. Nevertheless, even today the management of discarded electronic appliances is not taken place in a controlled way, resulting to uncontrolled collection by street vendors and to their promotion to metal and alloy recovery units.

4.2. European Union

In the European Union, e-waste has been targeted regarding the prevention of environmental pollution, for the exploitation of resources and the reduction of landfill use. The legislation developed by the European Parliament is based on three axes, the prevention, recycling and re-use of e-waste, so that the amount of the waste electrical and electronic equipment available is reduced [19]. The above are elaborated in two relative Directives:

1. Directive 2002/95/EC (RoHS-Restriction of Hazardous Substances) restricts the use of hazardous substances introducing the requirement for change of substances causing the main environmental problems during the

emplacement and recycling of the waste electrical and electronic equipment. According to this directive, the most effective way to ensure the substantial reduction of health and environmental hazards relating to hazardous substances is their replacement with other, safer substances. The prohibition of use of hazardous substances is most likely to increase the possibilities and the financial profit from recycling electrical and electronic equipment.

2. Directive 2002/96/EC on waste electrical and electronic equipment has been developed particularly to assist in reducing the waste electrical and electronic equipment available in the landfills and encourage the more efficient use of resources through recycling and re-use. The specific directive measures for collection, management, recovery and recycling of all electrical and electronic products and focuses on the Extended Producer Responsibility (EPR). Its main points are:

• The study and production of electronic equipment should facilitate the disassembly and recovery for posterior use and recycling of e-waste.

• The e-waste should be collected separately from other forms of waste and their collection should not burden households.

• The target price to integrate in the management system is 4 kg/year/resident.

• By the end of 2006, producers should be able to recover and reuse a certain target percentage for each of the 10 categories of the Directive ranging between 50-80%.

• Producers are responsible for financing e-waste collection and management.

4.3. Switzerland

Switzerland was the first country in the world where an official e-waste management system was established and operated [20]. The legislation regarding e-waste management was introduced for the first time in 1998 through ORDEA law (Ordinance on “The Return, the Taking Back and the Disposal of Electrical and Electronic Appliances”) [11, 21]. Two different e-waste recycling systems are active in the country. One is run by SWICO Recycling Guarantee (The Swiss Association for Information, Communication and Organizational Technology) and manages the “brown” electronic equipment (e.g. computers, televisions, radios, etc.), while the other is run by S.EN.S (Stiftung Entsorgung Schweiz System) and manages the “white” electrical equipment (e.g. washing machines, refrigerators, ovens, etc.) [20]. More specifically, consumers return the e-waste in a more convenient way, either through specified collection points, of retail companies or transporting the waste straight to the recycling spots. The materials are transported from the collection points to the disassembly facilities, in order to disassemble and disinfect e-waste, by removing the most toxic factors. In the recycling facilities, e-waste pass through an even more detailed disassembly, shredding and sorting, resulting mostly to the collection of plastic, glass, steel, aluminum and copper. Most of the recycled materials are then sent to refineries or foundries for the final material recovery. The remaining materials that cannot be recovered are led into incinerators for energy recovery and a small quantity, usually smaller than 2%, ends up to landfills. In the Swiss system, producers are fully responsible for the application and operation of the management system and the entire system is financed through a special recycling charge included in the product’s price [11]. Retailers, importers and manufacturers are obliged to take back their products free of charge and manage them in an “environmentally tolerable way” [21]. Approximately 75 Kt of electrical and electronic equipment have been collected, classified, disassembled

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and then processed in Switzerland in 2004, as a result of the effort of these systems [13], while approximately 68 Kt were collected in 2003 [20].

4.4. Japan

In the Japanese e-waste management system the withdrawal is not free of charge, but consumers pay an amount of money when they return used electronic products to the traders. Japan has established a withdrawal system for four types of e-waste (air conditioners, televisions, refrigerators and washing machines) since 1998. The law specifies target rates and imposes strict penalties for non-compliance [11]. Until 2004 there were 41 e-waste recycling facilities in Japan, partially financed by the ministries, municipalities or Japanese companies producing electronic products. Producers implement in their business strategy the e-waste management and have their own facilities or collaborate with other producers to create and operate such facilities. E-waste coming from residencies are collected when these products are not used anymore or when consumers buy new ones. The collected waste is transported to the intermediate 380 e-waste collection points and eventually to the facilities through a distribution system [22]. A basic characteristic of the Japanese system is the use of the primary disassembly procedure of big parts initially with a more accurate and brief process so that they handle the residues in a more proper way. Therefore, the Japanese companies of electronic equipment were the first ones to evolve welding without insulation and the electrical panel board connections without bromide compounds in relation to the European guidelines of the Directive RoHS, while they constantly aim at the designing of lighter products, cheaper and easier to be recycled. They plan the disassembly by reducing the number of the plastic resins in their products and reuse their parts [21]. Equivalent legislation is in force also for the collection and recycling of used electronic computers since 2003. The legal framework provides for two different categories for the used electronic computers. For those bought before October 2001, recycling is financed with 20-30€, while for those bought after October 2001, the recycling costs are included in the price of the product as an additional recycling tax. This legislation also directs on order the manufacturers to recover their corresponding products after they have been used by their last owners. This system is an example for the individual responsibility of producers, from the moment they have the natural and financial responsibility for their products recycling. Nevertheless, it should be noted that the e-waste recycling system success in Japan is based on social responsibility, environmental sensitivity and general discipline of Japanese people vis-à-vis regulations.

5. Conclusions

Electronic equipment and therefore e-waste are everywhere in our society. They are characterized by a complex chemical composition and difficulty in quantifying their flows at a local and international level. The pollution caused by their irregular management substantially degraded the environment mostly in poorer countries, receiving them for recycling and recovery of their valuable metals. As for the consequences on ecosystems, human health and environmental restoration of areas burdened by certain polluters generated by e-waste (e.g. Li and Sb), there are no

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sufficiently documented scientific studies. Motivated by the minimization of environmental effects caused by the generated e-waste, many technological changes have been effectuated. The following are indicated:

• The replacement of CRT screens with LCD screens (Pb elimination but Hg introduction),

• The introduction of optical fibres (Cu elimination from the cablings, but F, Pb, Y and Zr introduction),

• The introduction of rechargeable batteries (Ni, Cd reduction, but Li increase), etc.

Non-governmental organizations and citizens movements press for the elimination of hazardous substances in electronic appliances, resulting to manufacturers competing for a more "green" profile. Some indicative results of the above pressures are:

• The production of "halogen-free" appliances, not contributing to the production of PCBs and dioxins (but their production is more expensive environmentally),

• The replacement of bromide combustion retarders with more environment-friendly ones based on phosphorus, and

• The introduction of legislative restrictions (Pb, Hg, Cr, PBBs and PBDE up to 1000 mg/kg, Directive RoHS - Restriction on Hazardous Substances).

Summarizing the above, e-waste separation from the rest of solid waste and their recycling for the recovery of valuable raw materials and basic metals is essential. The management system has to be rationally designed so that the environmental benefits from the collection, transportation, management and the financial benefits from the recovery are not set-off by the required resources and energy consumptions for the system operation.

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