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The challenge of electronic waste (e-waste) management in developing countries

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Information and telecommunications technology (ICT) and computer Internet networking has penetrated nearly every aspect of modern life, and is positively affecting human life even in the most remote areas of the developing countries. The rapid growth in ICT has led to an improvement in the capacity of computers but simultaneously to a decrease in the products lifetime as a result of which increasingly large quantities of waste electrical and electronic equipment (e-waste) are generated annually. ICT development in most developing countries, particularly in Africa, depends more on secondhand or refurbished EEEs most of which are imported without confirmatory testing for functionality. As a result large quantities of e-waste are presently being managed in these countries. The challenges facing the developing countries in e-waste management include: an absence of infrastructure for appropriate waste management, an absence of legislation dealing specifically with e-waste, an absence of any framework for end-of-life (EoL) product take-back or implementation of extended producer responsibility (EPR). This study examines these issues as they relate to practices in developing countries with emphasis on the prevailing situation in Nigeria. Effective management of e-waste in the developing countries demands the implementation of EPR, the establishment of product reuse through remanufacturing and the introduction of efficient recycling facilities. The implementation of a global system for the standardization and certification/labelling of secondhand appliances intended for export to developing countries will be required to control the export of electronic recyclables (e-scarp) in the name of secondhand appliances.

Keywords: E-waste, crude recycling, Nigeria, waste management, developing countries, wmr 1178–9

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Introduction

The product life cycle, especially for electronic products, has reduced significantly in recent years due to rapid advances in technology. In particular the rapid growth in information technology and telecommunications has led to an improvement in the capacity of computers but simultaneously to a decrease in the products life time (Oh *et al.* 2003). This situation results in increasing number of obsolete products that cause environmental concerns due to the rapid depletion of waste disposal capacity (Kang & Schoenung 2004).

Table 1: Growth in teledensities.

Region	Population	GDP per million capita (US$)	Teledensity		
	2003	2002	1995	2001	2003
World	6130.42	5393	12.29	17.19	41.42
Africa	825.45	663	1.77	2.62	8.66
Nigeria	123.31	409	0.39	0.43	3.35

Source: ITU Database cited in Ndukwe 2006.

Table 2: Number of fixed and mobile lines in Nigeria, 1998–2004

	1998	2002	2003	August 2004
Fixed telephone lines	438 619	702 000	724 790	900 000
Mobile lines	20 000	1607 931	3149 000	5100 000
Total	458 619	1309 931	3873 790	6000 000

Adapted from BAN, 2005.

In Nigeria, there has been a phenomenal growth in the information and telecommunications technology (ICT) sector in the last decade. More and more Nigerians today have access to computer facilities at home, school, business centres and Internet cafes. A greater number also have access to mobile telephones and this is now playing a huge role in the development of the Nigerian economy. In less than 6 years, the Global System for Mobile Communication (GSM) has emerged as an integral and essential part of the culture and life of Nigerians. The teledensity in Nigeria grew from 0.39 in 1995 to 3.35 in 2003 (Table 1). For example, mobile phone subscription has increased from a mere 20 000 in 1998 to more than 6 million by the end of August 2004 (Table 2) and then to about 27 million by the end of 2006 (Ndukwe 2006).These advancements in ICT depend to a large extent on second-hand/refurbished electrical and electronic equipment (EEE), such as personal computers (PCs) and accessories, and mobile phones. There is also a large in-flow of other second-hand EEE such as dish-washers, radio sets, TV sets, electric kettles, printers, copiers, etc. into the country. Used PCs can be obtained for as low as 30% of the cost of a new product of similar brand. The introduction of the GSM into the country led to the preference of mobile telephony by more people in comparison with fixed lines because of widespread coverage and better services. As a result, most people have abandoned their fixed telephone services. This has resulted in large quantities of obsolete telephone sets that have either been thrown away or stored for perceived value.

The material flow of used (second-hand) PCs, accessories and other e-scrap from the developed countries into developing countries has been documented by the Basel Action Network (BAN) in conjunction with Silicon Valley Toxicity Coalition (SVTC), the Greenpeace and other environmental groups in Asia such as the Toxic Links (BAN/SVTC 2002, Toxic Links 2003, BAN 2005, Greenpeace 2005). Substantial quantities of electronic waste (e-waste) are also generated locally in the developing countries. These disused or obsolete/scrap EEE are not collected for appropriate EoL treatment in most developing countries. The inappropriate management of end-of-lie (EoL) waste EEE (WEEE) results in depletion of raw materials and pollution of the environment. In developing countries, WEEE are managed through various low-end management alternatives such as product reuse, conventional disposal in landfills, open burning and crude 'backyard' recycling (Furter 2004). Sound EoL management practices through value-added product recovery (repair and remanufacturing), material recovery (recycling) and energy recovery (incineration) and, as a final option, disposal in landfill (using appropriate landfill technology) are required for effective management of EoL electronics.

In the present study, we review the challenges facing solid waste management experts from the increasing in-flow of electronic waste into the developing countries in an attempt to bridge the so-called "digital divide". The material generation of e-waste across the developed countries and the destination of such toxic wastes were reviewed. The present management practices in the developing countries were also discussed and the environmental and health consequences outlined.

ICT development and global e-waste flows

Economics of second-hand EEE

Environmental impacts associated with production and disposal of PCs are exacerbated by their short lifespan: it increases demand for production of new units and ultimately adds to the number of computers destined for landfills or recycling (Williams 2003). The typical life of a PC in the workplace is approximately 2–3 years, while in the home the typical life is 3–5 years (Boon *et al.* 2001). As these PCs become obsolete, they are replaced and the old PCs are disposed of. The main reason for this short lifespan is no doubt the rapid technological progress in computer performance. Secondhand EEE especially PCs can be reused and are usually preferred by those who cannot afford new systems. Not all users of computers require high performance; most of the popular applications of computers (e-mail, web, office software) work well on older machines. Computer users can be roughly divided into two groups: normal and power users. Normal users are interested in using a computer for email, web-browsing and applications such as word-processing and spreadsheets. These applications are not very hardware intensive by recent standards and can be satisfactorily handled by computers even 5 years old. In addition to the above, power users also use graphic/hardware intensive applications such as video/image editing and games. These users like to update computers every year or two to keep near the state-of-the-art (Williams 2003). With the implementation of the WEEE Directive in Europe and similar legislations/regulations in other developed countries, there will be more WEEE to be handled in the coming years in these developed countries. As a result more WEEE exports should be anticipated.

The used PC market is primarily driven by market forces. The demand for used PCs can also be viewed in terms of differences in the purchasing power among customers. Those needing to cut costs are motivated by lower prices to choose the used goods. The extension of lifespan of PCs should be a priority in the environmental management of computers. Williams (2003) observed that one important and practical way to do this is through encouraging the market for used PCs. Computers are normally disposed of before they become dysfunctional; rather the user is making space for a new machine with better specifications. Such 'used' products should, however, be certified functional and appropriately labelled prior to export. Otherwise such trade will amount to trade in hazardous waste.

For many products, environmentalists assume that reuse is environmentally beneficial because it replaces the manufacturing and purchase of new goods. Manufacturers may oppose this type of reuse for the same reasons. Thomas (2003) observed that there is a rich economic literature on planned obsolesce, the incentives of producers to alter the durability of their products, and the circumstances that promote or inhibit second-hand markets. The idea that producers might want to decrease the durability of their goods in order to induce customers to replace their goods more frequently is consistent with the idea that reuse of products reduces the demand for new products. Factors that affect the reuse of products extend beyond durability *per se* and include manufacturers' practices with respect to product maintenance, access to spare parts, software upgrades and compatibility, and copyright protection (Thomas 2003).

The impact of second-hand goods on the sales of new goods can be developed through an economic model of the second-hand market. Thomas (2003) developed a simplified model to explain this phenomenon. He, however, observed that some of the used sales come from people, who would have bought new products, and some of the used sales come from people who previously would not have bought. The overall environmental impact of second-hand market sales depend both on the extent to which second-hand sales replace the sales of new goods, as well as on the overall size of the second-hand market.

ICT development and the environment

Information and telecommunication (IT), and computer networking has penetrated nearly every aspect of modern life. The resulting increase in digitally enabled human connectivity is evidenced by the size of the internet. In 2001, there were over 300 million internet users worldwide and this was estimated to increase to more than 500 million users by 2003 (Fichter 2003).Internet access in Nigeria increased from about 100 000 users in 2000 to close to 2 million users by the end of 2004 (Table 3).

In our ever-changing technological age, EEE continue to develop at an astounding rate. In spite of the slow down of the world's economy, the rate at which EEE goods are being produced is enormous. All the indications are that this market will continue to grow, particularly with improvements in technology. This growth has brought to light concerns over environmental effects of materials used in the market (Landry & Dawson 2002). Various electrical and electronic devices have been confirmed hazardous using the toxicity characterization leaching procedure (TCLP) (Musson *et al.* 2000, Li *et al.* 2006). At their EoL, these devices are expected to be treated as hazardous waste. To overcome the cost implications of landfilling these hazardous items or recycling some of the EEE components [especially cathode ray tubes (CRT), which

Table 3: Growth in Internet use in Nigeria.

Year	Internet users	Internet penetration (%)	Growth in internet users (%)
2000	107 194	0.1	–
2001	152 350	0.1	43.06
2002	420 000	0.3	173.88
2003	1613 258	1.3	284.11
2004	1769 661	1.5	9.69

Data adapted from BAN 2005.

contain high levels of lead], these items are collected by 'recyclers' for recycling. Roman & Puckett (2002) observed that the so-called recycler acts more as 'waste brokers'. Rather than recycle these waste items, these collected hazardous waste materials are exported to the developing countries usually 'as is' without testing for functionality. This is because recycling is hardly profitable.

The quickly developing and rapidly growing ICT sector poses several threats to sustainable development. Large amounts of natural resources are involved in the life cycle of ICT products and hazardous waste materials are generated. The increasing demand for consumer electronics and electric products combined with the accelerated pace at which technology is evolving, has inevitably resulted in an increased amount of obsolete, discarded, broken or abandoned products that must be treated by society (Hula *et al.* 2003). Even though the size and weight of ICT hardware has reduced dramatically, its growing total volume has considerably increased the absolute resource consumption and toxic waste (Plepys 2002). Consumer electrical and electronic equipment are of particular concern due to high production volume and characteristic short-term scales of technology or stylistic obsolesce leading to landfilling of large amounts of discarded products. Exacerbating this problem is the fact that components in these products are typically required to fit into a tight enclosing space, which makes disassembly for component recovery a challenging task (Hula *et al.* 2003).

The overall IT market is driven by the dual needs for mobility and light weight of components. This is reflected in the following items.

1. Laptops accounting for over 40% for new computer sales, a rate which is increasing.
2. LCD flat screen monitors accounting for 90% of desktop computer sales. CRT monitors are currently only being used in sectors that require a high degree of colour accuracy, such as graphic design, but CRTs will soon be replaced for those uses as technology continues to improve (AIIA 2005).

There are a number of issues throughout the EEE life cycle, from material extraction and component and product manufacture, to energy requirements in the use and disposal of products at the end of their life. This is compounded by the fact that in recent years, EEE has increased in technological complexity, with new product innovations and ever-shortening product life expectancy (Darby & Obara 2005). The low economic value of the material composition, high rate of material mixing, and low levels of toxic materials have also discouraged efforts to fully recycle consumer electronic products.

There has therefore been a growing concern over the potential impacts posed by the disposal of waste PCs and other WEEE (Monchamp 2000, Musson *et al.* 2000). This concern stems from two factors: the volume of WEEE expected to become waste as new, more advanced products enter the market and the presence of certain toxic and hazardous substances in WEEE that may be released into the environment upon disposal. These concerns have resulted in attempts at recycling WEEE including the plastic components. Life cycle analysis of the environmental impacts of recycling of EoL WEEE in Switzerland using state-of-the-art recycling facilities, showed that throughout the complete recycling chain, the sorting and dismantling activities are of minor interest; instead the main impact occurs during the treatment applied further downstream to turn the waste into secondary raw materials (Hischier *et al.* 2005).

EEE industry and the developing countries

Increasing globalization and production outsourcing are the two clear trends in today's economy. Free trade agreements are covering more and more countries and the economic growth and rapid technology expansion have facilitated the spread of high-tech industries across the globe.

The electronics industry is where outsourcing of manufactured products is practiced by most of the companies. Most original equipment manufacturers have disintegrated their vertical manufacturing chains and labour-intensive activities. Their main activity is now focused on product design, branding and supply chain management and manufacturing is partly or entirely outsourced to contract manufacturers or component suppliers, who have adequate know-how and technological capabilities and are able to reduce production costs by utilizing the economics of scale. The majority of labour-intensive production activities, such as sheet metal processing, machining, injection moulding, printed circuit board fabrication and assembly, have moved to developing countries or economies in transition, where labour cost is lower. As a result most of the electronic manufacturing companies are today concentrated mainly in the Pacific Rim countries such as Singapore, South Korea, Malaysia and other Asian countries, such as India, Taiwan-China and Mainland China (Plepys 2002).

For example, exports from the EEE sector earned China US$ 227.46 billion in 2003 accounting for 51.9%of the countries total export value. Of these exports, approximately 25% went to the EU (Hicks *et al.* 2005). This export to the EU indicates concerted attempt at full compliances with the WEEE and RoHS directives by the Chinese EEE industries.

Similarly, the majority of the EoL activities of EEE are taking place in the developing countries. The disposal by landfilling, incineration, recycling and material recovery- are taking place in the developing countries especially in the Asia-Pacific axis. A greater percentage of obsolete/discarded EEE collected for EoL management are exported to the developing countries. In these countries, there is a high level of repair and reuse activities. This returns obsolete EEE to a 'second life'. The unserviceable/unusable EEE or modules are usually disassembled (incomplete disassembly) for component retrieval and reuse in repair activities, disposed with municipal solid waste or recycled using crude processes. High-level material recovery/recycling from EoL WEEE are currently taking place in Asia. In Africa, semi-formal recycling of WEEE is taking place only in South Africa (Finlay 2005). The environmental and health implications of this low-end management of WEEE are enormous. State-of-the-art recycling facilities for WEEE exist in many European countries and in North America. However, it is not possible to recycle WEEE without causing any environmental impact. The treatment of WEEE to produce secondary raw materials from them causes considerable environmental impact. However, the impact is much smaller than that from the respective primary production, or incineration or landfilling of WEEE (Hischier *et al.* 2005, Scharnhorst *et al.* 2005).

E-waste in context

E-waste generation by country

Electrical and electronic equipments (EEE) cover a broad spectrum of products used by businesses and consumers. As defined in the WEEE directive (2002/96/EC), EEE includes equipment that is dependent on electric currents or electromagnetic field in order to work properly, and include equipments for generation, transfer and measurement of such currents and fields. It applies to products that are designed for use with a voltage rating not exceeding 1000 V for alternating current and 1500 V for direct current. EEE is further divided into 10 categories of waste under the EU WEEE Directive as shown in Table 4 (Van Rossem 2002, Widmer 2005, Yla-Mella *et al.* 2006).

The rapid growth in ICT has led to an improvement in the capacity of computers but simultaneously to a decrease in the product's lifetime such that the volume of waste generated is increasing by 10% annually, (Oh *et al.* 2003). In 1996, the computer and electronics industry composed 11% of the gross domestic product (GDP) in the US, and was growing at an annual rate of 4% with computer sales rising to 15% annually (Musson *et al.* 2000). Consumer electronics are the fastest growing sector of municipal solid waste (MSW) in both developed and developing countries and is arguably one of the most toxic. It has been estimated that 500 million PCs worldwide reached the end of their life in the decade between 1994 and 2003 (Widmer *et al.* 2005, Dickenson 2006). This volume of obsolete PCs contain approximately 2 870 000 tons of plastics, 718 000 tons of lead, 1363 tons of Cd and 287 tons of mercury (BAN/SVTC 2002, Widmer *et al.* 2005, Dickenson 2006).

Table 4: WEEE categories according to the EU WEEE Directive.

WEEE category	Label
Large household appliances	Large HH
Small household appliances	Small HH
IT and telecommunication equipment	ICT
Consumer equipment	CE
Lighting equipment	Lighting
Electrical and electronic tools*	E & E tools
Toys, leisure and sports equipment	Toys
Medical devices**	Medical equipment
Monitoring and control instruments	M & C
Automatic dispensers	Dispensers

*With the exception of large-scale stationary industrial tools.
**With the exception of all implanted and infected products.
Source: Antrekowitsch *et al.* 2006.

In the US it accounted for 2.63 million tons of waste in 2005 (or 1.1% of the waste stream), an increase of 7.8% over 2004. Of this volume, 87.5% was disposed rather than recycled (INFORM 2006).Between 1981 and 2005, more than 1 billion PCs have been sold worldwide – 400 million of those in the United States. In 2003 alone, more than 50 million computers were sold in the US (Gattuso 2005). It is estimated that between 14 and 20 million are retired annually in the US (Boon *et al.* 2001, Gattuso 2005, Kumar *et al.* 2005). In the UK (Western Europe) in 1998, 6 million tons of WEEE was generated accounting for 4% of the MW stream. Increasing at 3–5% a year, WEEE generation in the UK is estimated to hit 12 million tons by 2010 (Cui & Forssberg 2003, Darby & Obara 2005).

The volume of waste computers generated in South Korea in 2002 were estimated at 1.2 million and was predicted to double, reaching 2.2 million by 2005 (Oh *et al.* 2003). Germany has a yearly electronic scrap waste stream of about 1.8 million whereas in Austria, the total e-scrap amounts to about 85 000 tons per year (Antrekowitsch *et al.* 2006). It is estimated that approximately 300 000 scrap PCs are generated each year in Taiwan (Lee *et al.* 2000). Liu *et al.* (2006) estimated that about 1.6 million obsolete EEE were generated in 2003 in China with TV accounting for nearly half of the total. WEEE generation in some countries is shown in Table 5. There is dearth of data on the generation of WEEE in the developing countries, especially in Africa.

Destination of e-waste

It has been estimated that about 20 million computers enter the market every year in the USA and 12 million computers

Table 5: WEEE generated in selected countries.

Country	E-waste generated (tons year^{-1})	Category of appliance counted in e-waste
Switzerland	66 042	Office and telecommunications equipment, consumer entertainment electronics, large and small domestic appliances, refrigerators
Germany	1100 000	
UK	915 000	
USA	2124 400	Video products, audio products, computers and telecommunications equipment
Taiwan	14 036	Computer, home electrical appliances
Thailand	60 000	
Denmark	118 000	
Canada	67 000	Computer and consumer electronics

Source: cited in Kumar *et al.* 2005. http://www.ewaste.ch/factsandfigures/statistical/quantities/.

are disposed every year, and out of these, only about 10% are remanufactured or recycled (Ravi *et al.* 2005). The US e-waste recycling industry are reported to have once declared that about 80% of the e-waste they received was exported into Asia, and 90% of this went to China (BAN/SVTC 2002, Hicks *et al.* 2005, Antrekowitsch *et al.* 2006). The destination of un-recycled e-waste in the developed countries includes landfills, incinerators or export to developing countries.

Antrekowitsch *et al.* (2006) observed that 'up to 90% of e-scrap was land filled in 2003, even in the developed countries. Due to concerns over environmental pollution as a result of the toxic and hazardous materials contained in e-waste, concerted efforts have been made at diverting these toxic materials from landfills'. Today, a large proportion of European and North American WEEE are exported – in some cases illegally – to Asia, with China being one but not the only destination (Hagelekun 2006a)

Estimates show that South Korea exports about 1.8 million used computers to China each year, to escape paying the steep recycling and disposal costs within its own borders (Toxic Dispatch 2004). A documentary study – Exporting Reuse and Abuse to Africa – coordinated by BAN and SVTC revealed that about 500 container loads of second-hand PCs and accessories enter Nigeria through the Lagos ports monthly, with each container containing about 800 monitors or CPUs. This amounts to about 400 000 second-hand or scrap units. The study observed that up to 75% of these materials imported for reuse are unusable junk that are non-functional or irreparable. From tags on the computers and information on the hard drives, the BAN study estimated that about 45% of these imports were from the EU, 45% from the US, while the remaining 10% were from other locations such as Japan, Belgium, Finland, Israel, Germany, Italy, Korea, the Netherlands, Norway and Singapore (BAN 2005).

Roman & Puckett (2002) observed that most of the e-scrap recycled in Guiyu, China is of North American origin, with Japanese, South Korean, and European waste witnessed to a lesser degree. Similar studies by Basel Action Network (BAN), Silicone Valley Toxicity Coalition (SVTC), Greenpeace and Toxic Links reveal large-scale export of e-scrap to developing countries and the environmental and health implication of the various low-end management alternatives such as product reuse, conventional disposal in landfills, open burning and crude 'backyard' recycling (BAN/SVTC 2002, Toxic Links 2003, BAN 2005, Greenpeace 2005).

Studies such as the BAN/SVTC study of e-waste recycling in developing countries have instigated an international campaign to ban further exports of e-waste to developing countries and to force manufacturers to take back and recycle their products. Gattuso (2005) observed that the thousands of tons of computers and other electronics shipped out of the US to developing countries is the direct result of the 'rush' to ban desktops and other electronics from landfills in the US. The publication opined that the US computer recycling market is not big enough to handle the large mount of e-waste generated, which are being increasingly banned from municipal landfills. Gattuso (2005) noted this is not the case in developing countries where markets for electronic components and recyclables thrive due to the large demand for labour; whereas the cost to recycle a home computer in the US is US$ 20; it is only US$ 4 in developing countries such as India. For the markets in these poor countries, working 'in such recycling facilities and being exposed to health dangers' can mean the difference between making a living and remaining unemployed. The report also observed that the cost of recycling 1 ton of e-waste in the US can be as high as US$ 500 compared to the cost of landfilling, which is only US$ 40.

Widmer *et al.* (2005) also reported statements credited to Larry Summers, the then Chief Economist of the World Bank, in 1991 while speaking on the economic sense of exporting first world waste to developing countries. He was credited to have argued (amongst other issues) that:

- "the least developed countries, especially those in Africa, were seriously under polluted and thus could stand to benefit from pollution trading schemes as they have air and water to spare; and that
- environmental protection for 'health and aesthetic reasons' is essentially a luxury of the rich, as mortality is such a great problem in these developing countries that the relative minimal effects of increased pollution would pale in comparison to the problems these areas already face."

From the foregoing, there are strong indications that some individuals or organizations are visibly in support of, or are encouraging the export of e-waste to developing countries where 1 ton of e-waste can be landfilled without a charge or recycled with 'profit' irrespective of the environmental or health consequences.

Component and material contents of WEEE

In the mid-1990s, a typical desktop system was observed to consist of the following components: silica (24.9%), plastics (23%), iron (20.5%), aluminum (14.2%), copper (7%), lead (6.3%), zinc (2.2%), and tin (1.0%). All other constituents (including cadmium, chromium, antimony, and beryllium) were found to be present in percentages less than 0.1%. The most common plastic used were acrylonitrile butadiene styrene (ABS) (57%), polyphenylene oxide (36%), high impact polystyrene (HIP) (5%), and polycarbonate/acrylonitrile butadiene styrene blend (PC/ABS) (2%) (Milojkovic & Litovski 2005). The material fraction of e-waste collected and recycled in Switzerland is given in Table 6.

The composition of e-scrap depends strongly on the type and the age of the scrap. For example, scrap from IT and telecommunication systems contain a higher amount of precious metals than scrap from household devices. In older devices, the content of noble metals is higher but also the content of hazardous substances than in newer devices (Antrekowitsch *et al.* 2006). E-waste contains considerable quantities of valuable materials such as precious metals. Early generation PCs each used to contain up to 4 g of gold, however, this has decreased to about 1 g today (Widmer *et al.* 2005).

Table 6: Material fractions in E-waste (as reported by a recycler in Switzerland).

Component	Percentage composition
Metals	60.2
Plastics	15.21
Screen (CRT and LCD)	11.87
Metal–plastic mixture	4.97
Pollutants	2.70
Cables	1.97
PCBs (also known as PWBs)	1.71
Others	1.38

Source: cited in Widmer et al. 2005.

The material of most concern in e-waste is lead. Studies indicate that lead may constitute up to 6.3% of a typical PC. Every computer, including the monitor, on average contains between 1 and 2 kg of lead (Milojkovic & Litovski 2005). Lead is used in primary PC applications; it makes up to 37% of the tin–lead solder that connects computer chips to the printed wiring boards (PWBs), it is used as a radiation shield in monitor glass (20% of the weight of the monitor is lead), and it is sometimes used as a plastic stabilizer in PVC cabling (Monchamp 2000). Other substance of environmental health concerns in WEEE include heavy metal such as cadmium, chromium, mercury, antimony and brominated flame retardants (BFRs) such as polybrominated diphenyl ether (PBDE), and polybrominated biphenyls (PBB).

Management issues in developing countries

Present management activities

Informal recycling of waste electronic goods in developing countries is emerging as a new environmental challenge for the twenty-first century. Investigations by environmental groups such as Basel Action Network (BAN), the Silicon Valley Toxicity Coalition (SVTC), Greenpeace, Korea Zero Waste Movement Network (KZWMN), and Toxic Links reveal that significant quantities of highly polluting hazardous electronic waste are still illegally pouring into developing countries and that home-grown recycling activities are wreaking environmental havoc.

These ground breaking studies and documentaries reveal that e-waste is usually processed by 'backyard' industries under the most primitive of processes (Williams 2005). E-waste dumping in developing countries has been criticized by environmentalists at various fora around the world. These activities point out that the confirmed dumping of electronic scrap and other kinds of waste in the developing countries by the developed countries not only contravenes the Basel Convention in the trans-boundary movement of hazardous wastes, but also allows electronic manufacturers to evade their responsibilities over the ultimate fate of the products they put out in the market (Toxic Dispatch 2004).

The potential environmental disaster over e-waste flow into developing countries will be increased not only due to the huge amount of the e-waste but also by the improper treatment methods. In China, most of the e-waste recycling and disposal operations such as open burning of plastic waste, exposure to toxic solders, river dumping of acids and widespread general dumping are quite polluting and likely to be very damaging to the ecology and human health (ECOFLASH 2003).

Currently, the majority of e-waste in China and other developing countries are processed in backyards or small workshops using primary methods such as manual disassembly and open burning (Liu *et al.* 2006). The appliances are stripped of their most valuable and easily extracted components such as PWB, CRTs, cables, plastics, metals condensers, and the worthless materials such as batteries, liquid crystal displays (LCDs) or wood. These fractions are processed to directly reusable components and secondary raw materials in a variety of refining and conditioning processes. The remaining parts are dumped or stockpiled directly (Liu *et al.* 2006).

Repair and reuse activities

The second-hand or e-scraps exports into developing countries are rarely tested for functionality, up to 75% of such exports entering Nigeria are unusable junks. As a result there is high level of repair and reuse activity in Nigeria. At the computer village in Lagos the hub of second-hand EEE in Nigeria, BAN observed that there are about 3500 registered businesses involved in all manner of sales and repair of computers, phones, peripherals and software. BAN observed that about half of the businesses located at the computer village are involved in refurbishment and repair of imported used IT equipment and parts.

Disposal with municipal solid waste

Management of discarded electronics in the developing countries is taking place through traditional methods of MSW management, namely landfilling and incineration.

Up to 90% of e-scrap was landfilled in 2003, even in the developed countries (Antrekowitsch *et al.* 2006). A tremendous amount of e-waste exported into the developing countries and the processed residues are not recycled but simply dumped. Materials dumped include leaded CRT glass, burned or acid-reduced circuit boards, mixed dirty plastics including Mylar and videotapes, toner cartridges and considerable material apparently too difficult to separate. Residues from recycling operations including ashes from numerous open burning operations and spent acid baths and sludge are also dumped (Roman & Puckett 2002). Obsolete electronic devices in Nigeria are usually stored for a while for a perceived value (physical or emotional) before disposal with municipal waste. In government agencies and some private establishment, these items are usually stored in basements or in storerooms until directives are issued for their disposal. Because of the absence of a special framework for the separate collection and management of e-waste in Nigeria, these devices are disposed with MSW at open dumps and into surface waters. Our survey at selected towns in Nigeria (Lagos, Benin and Aba) indicated there are no attempts at recovering materials from e-scrap using crude processes. A typical example of which is the open burning of copper wire and other cable and EEE components to salvage copper. However, there are indications that waste collectors have also started collecting selected components of EEE, especially the printed wiring board, for export probably to Asia for recycling.

Crude recycling

Informal dismantling and recycling of e-wastes, the so-called 'backyard activities' is emerging in developing countries. Crude recycling activities are taking place in Asia and Africa aimed at material recovery from e-waste. In these regions, e-scrap is mostly treated in 'backyard operations' using open sky incineration, cyanide leaching and simple smelters to recover mainly copper, gold and silver with comparatively low yields (Hagelekun 2006a). The BAN Study 'Exporting Harm, the High-tech Trashing of Asia' described the crude recycling activities taking place in China and other Asian countries. For example, wires are collected and burned in open piles to recover re-saleable copper. Circuit boards are treated in open acid baths next to rivers to extract copper and precious metals (Roman & Puckett 2002, Williams 2005). A pilot program conducted by the US EPA that collected scrap in a state in the US (San Jose, CA)estimated that it was 10 times cheaper to ship CRT monitors to China than it was to recycle them in the US (Roman & Puckett 2002).

These crude methods result in loss of resources, energy wastages and environmental pollution. Moreover, such 'backyard recyclers' do not have wastewater treatment facilities, exhaust/waste gas treatment and personal health protection equipment (Roman and Puckett 2002; Liu *et al.* 2005). Unfortunately, most of the participants in this sector are not aware of the environmental and health risks and do not know better practices or have no access to investment capital to finance even profitable improvements or implement safety measures (Widmer *et al.* 2005).

Besides the tremendous adverse effects on environment and health in these regions, this also means a huge and mostly irreversible waste of resources. It is of particular irony if materials that had been collected, for example, in Europe under the WEEE directive aiming at fostering the environmentally sound reuse/recycling and to preserve resources finally ends up in such a 'recycling' environment (Hageluken 2006a). As long as these e-scraps are exported from Europe and North America to developing countries for crude recycling, it is unlikely that there will be sufficient incentives to invest in the necessary infrastructure for efficiently and safely recycling of e-waste in these developed regions (Roman & Puckett 2002).Infrastructure determines the process methods and amounts of waste that can be processed. Collection methodology, sorting and recovery technologies, material recycling processes and disposal methods are key factors in the comprehensive recycling of e-waste (Kang & Schoenung 2004).

Hicks *et al.* (2005) observed that there are number of reasons for the existence of large and effective informal WEEE processing sectors in developing or industrializing countries:

- In developing and industrializing countries waste is viewed as a resource and income-generating opportunity.
- There is a general reluctance to pay for waste recycling and disposal services, particularly when consumers can make some money by selling their old and broken appliances.
- Waste collection and disposal services in developing countries cost a higher proportion of the average income than in developed countries.
- There is lack of awareness among consumers, collectors and recyclers of the potential hazards of WEEE, crude 'backyard' recycling and other disposal practices.

Case reports of e-scrap trades and crude recycling

A recent investigation by the toxic trade watchdog (BAN) revealed that large quantities of obsolete computers, televisions, mobile phones, and other electronic equipment exported from the US and Europe to Lagos, Nigeria for 'reuse and repair' are ending up gathering dust in warehouses or being dumped and burned near residences in empty lots, roadsides and swamps creating serious health and environmental contamination from the toxic leachate and smoke. As mentioned earlier, the study observed that an average of 500 containers enter Nigeria through the Lagos ports monthly with each containing about 800 monitors or CPUs. This amounts to an average of 400 000 second-hand or scrap monitors or CPUs per month or 5 million units (60 000 tons) per year (Osibanjo & Nnorom 2007).

This report includes evidence of numerous computer identification tags from schools and government agencies as well as forensic examination of hard-drives picked up by BAN in Lagos, revealing very personal information about their previous owners (BAN 2005). Information left in these hard-drives may be one of the numerous sources of data collection for persons involved in cyber crime in Nigeria. These 'secret' personal data from second-hand computers exported to Nigeria may be 'fueling' the export of e-crime to the US and other developed countries (Osibanjo & Nnorom 2007). A positive correlation should be anticipated on analysis of data on the material in-flow of WEEE into the country and increase in cyber crime 'export' from Nigeria.

According to BAN, much of the trade is illegal under international rules governing trade in toxic waste such as the Basel Convention. Unfortunately, governments, particularly the US refuses to ratify; implement or properly enforce these rules for toxic electronic waste. Proper enforcement of these rules would require all such e-scrap exports, whole or in parts to be properly tested for functionality and certified to be going to 'reuse' destinations rather than for disposal or recycling. These trades are often justified under the name of 'bridging the digital divide'. This rhetoric is also used as excuses to obscure and ignore the fact that these bridges double as toxic waste pipeline to some of the poorest communities and countries in the world. While supposedly closing the 'digital divide' we are opening a 'digital dump' (BAN 2005).

The national laws of China, India and the Philippines have for several years now forbidden the importation of hazardous waste. The Basel Convention also bans the export of toxic waste from Organization for Economic Cooperation and Development (OECD) to Non-OECD countries, even for recycling purposes. Despite these prohibitions, however, electronic waste continues to arrive into these nations. Williams (2005) observed that despite significant attention from the media and enactment of some national level trade bans (most notably, China and India), the problem is apparently worsening.

The report by BAN/SVTC in 2002 – 'Exporting Harm: the High-tech Trashing of Asia' – showcases the Chinese town of Guiyu as an example of several environmental impacts that can be caused by informal recycling of electronics (BAN/SVTC 2002). Toxics Link, an Indian NGO, also published a report in 2003 arguing that similar problems are occurring in Delhi and other areas of India (Toxic Links 2004).In 1992, the Basel Convention banned the export of hazardous electronic wastes and in 1994, parties in the Basel Convention agreed to an immediate ban on exports of electrical and electronic scrap, including computers for final disposal in non-OECD countries. China also has other legislation banning the importation of waste electric and electronic appliances such as computers, television sets, monitors and CRTs (ECOFLASH 2003). Studies by the BAN, Greenpeace, and other environmental groups and NGOs are indicatives of very damaging toxic trades that the global community sought to prohibit in the late 1980s with the adoption of the Basel Convention.

These trade activities are illegal under the Basel Convention. Yet, it appears that too many governments are looking the other way and are failing in dramatic fashion to properly enforce and implement the convention for post-consumer electronic waste by failing to require adequate testing and labelling to certify functionality and quality of equipment to ensure that is does not equate to trade in hazardous waste (BAN 2005).

Economics of crude recyling

There are significant economic potentials if valuable materials in WEEE are recovered and sold in the market especially if the recovery activities are carried out in the developing countries where labour is cheap and environmental and health standards are lax or not enforced (Sodhi & Reimer 2001, Roman & Puckett 2002, Widmer *et al.* 2005).

The WEEE industry also provides income-generating opportunities for both individuals and enterprises, as waste is sold and traded among collectors, processors, second-hand dealers and consumers. For example, the extensive WEEE processing industry in Guiyu has been valued at US$ 72 million (Hicks *et al.* 2005).

More formal enterprises are developing an interest in WEEE recycling and processing in China and South Africa (Furter 2004, Hicks *et al.* 2005). In China new WEEE recycling and treatment facilities are planed and financed by both government and private companies. Certain advanced technologies have also been implemented in the recycling process in China (ECOFLASH 2003).

Pollution from present management practices

The actual operation of several end-of-life processes for e-waste such as landfill, incineration with MSW and mechanical recycling results in emissions of heavy metals and organic pollutants to air, water, soil and residual potentially hazardous waste. E-waste contains more than 1000 different substances, many of which are highly toxic (Widmer *et al.* 2005). WEEE is approximately 1% of total landfill, yet it is responsible for approximately 50–80% of the heavy metals in leachate (Chiodo *et al.* 2002). In addition, 70% of heavy metals (including Hg and Cd) found in the soil are of electronic origin (Milojkovic & Litovski 2005).

The processing of e-waste in developing countries is profitable because the labour costs are cheap and environmental regulations are lax in comparison with developed countries (Roman & Puckett 2002, BAN/SVTC 2002). Consequently, crude methods are adopted to reclaim metals and many kinds of pollutants are generated during these processes creating serious problems to ecological environment and human health. Studies at Guiyu, China revealed high levels of environmental pollution from crude recycling activities (Roman & Puckett 2002, Liu *et al.* 2006). Poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and polybrominated biphenyl ethers (PBDEs) were detected in environmental samples at levels up to 593, 733 and 2196 mg kg^{-1}, respectively (Leung *et al.* 2004 cited in Liu *et al.* 2006). Heavy metals Cu, Pb and Zn were also determined at levels up to 711, 190 and 242 mg kg^{-1}, respectively. Similar investigation by BAN at the same e-scrap recycling site (Guiyu, China) also indicated high levels of environmental contamination. Surface water, sediments and soil samples at one such site revealed alarming levels of heavy metals that correspond very directly with those metals commonly found in computers. Chromium, tin, and barium were found at levels 1388, 152 and 10 times (respectively) higher than the EPA threshold for environmental risk in the soil (Roman & Puckett 2002). Due to high levels of heavy metal pollution of surface and ground water in the town, Guiyu's drinking water has been delivered from a nearby town since approximately 1 year after the appearance of the WEEE industry over a decade ago (Hicks *et al.* 2005).

Health risk assessments are required for the analysis of the consequences of inappropriate management of end-of-life electronic wastes in developing countries. Yanez *et al.* (2002) recommend that such studies may need to consider the simultaneous exposure to metals and organic compounds, thus making experimental models necessary for the study of the toxicological interactions among such contaminants.

Challenges

Widmer *et al.* (2005) identified difficulties specific to developing and industrializing countries in WEEE management after assessing management issues from China, India, and South Africa. These difficulties are summarized below:

- "although the quantity of indigenous e-waste per capita is still relatively small (estimated to be less than 1 kg e-waste per capita per year), populous countries such as China and India are already huge producers of e-waste in absolute terms;
- these countries also display the fastest growing market for EEE;
- some developing and transition countries are importing considerable quantities of e-waste. Some of them arrive as donations to help 'the poor' while others are mislabelled."

The challenges facing EoL management of e-waste in developing countries are enormous and include the following items.

1. The increasing volume of e-waste imported illegally into the developing countries. Second-hand EEE imported into the developing countries are rarely tested for functionality. Thus significant quantities of used EEE imports estimated at between 25–75% are unusable junk (e-scrap)
2. Ignorance of the toxicity or hazardous nature of e-waste. There is lack of awareness in government and public circles of the potential hazards of the present EoL management of WEEE in the developing countries to human health and the environment. Those involved in the dangerous crude recycling activities are also ignorant of the

implications of these activities and/or are forced to choose between 'poverty and poison'.

3. There is absence of infrastructure for the recycling or appropriate management of e-waste following the principles of sustainable consumption/development. In Africa formal recycling facilities for e-waste exists only in South Africa (Finlay 2005)
4. Lack of funds and investment to finance profitable improvements in e-scrap recycling. There is loss of resources, energy wastages and environmental pollution as a result of the crude 'backyard' recycling activities. There should be economic incentives for environmentally sound practices and technologies. Recycling and treatment facilities require a high initial investment, particularly those fitted with technologically advanced equipments and processes (Hicks *et al.* 2005).
5. Absence of legislation dealing specifically with e-waste. There is also a near absence or ineffective implementation of existing regulations/legislation relating to the control of trans-boundary movement of hazardous wastes and recyclables.
6. Absence of mandated or effective voluntary take-back programmes (EPR) for end-of-life EEE in the developing countries. There is also the unwillingness of consumers and enterprises to hand out their obsolete EEE or pay for WEEE recycling.

Corruption and ineffective data collection and dissemination on material flow of EEE and WEEE are also hurdles to overcome in the developing countries especially in Africa. The introduction of extended producer responsibility with well-defined roles for all participants: producers, users, authority, and waste managers is essential for designing an effective e-waste management system.

Outlook

If e-scrap is landfilled or not treated in an environmentally sound manner, a high risk of environmental damage exists. Material recovery *per se* is not a solution in itself without considering the implied economic and environmental effects (Hagelekun 2006a). The development of small-scale and informal recycling processes for e waste has had serious adverse impacts on the environment and human health in some regions (Liu *et al.* 2006). Thus is in order to optimize electronics recycling, attention should be placed on maximizing eco-efficiency, i.e. the environmental and economical balance by maximizing physical recycling and revenue obtainable thereof, while minimizing environmental burden and total costs connected with the recycling chain (Hageluken 2006a,b).

New waste management options are needed to divert end-of-life electronics from landfills. However, there are several factors to consider in the development of a successful diversion strategy. This strategy must be based on its economic sustainability, eco-efficiency, technical feasibility, and a realistic level of social support for the programme. One aspect of the strategy should include recycling and re-use of end-of-life electronic products (Kang & Schoenung 2004). Efficient e-waste recycling can be either stimulated by the economical benefits or controlled by strict regulations (ECOFLASH 2003).

Generally, waste can be understood as a material resource from technosphere. It contains valuable as well as non-valuable materials, which are called in the mining industry, dead rock. There are economic as well as ecological gains if WEEE is recovered or reused. Recovering products at their EoL diverts wastes disposed in landfills and results in recaptured asset value from the recovered products.

Most countries in Europe and North America already have specific expertise in waste management and this can be used and shared to optimize learning and maximize the efficiency for implementing improvements in e-waste management. Widmer *et al.* (2005) proposed 'a knowledge partnership in e-waste management in the form of an International WEEE Conference Center. This partnership among developing and developed countries will offer the possibility to develop new models for e-waste management that will benefit users, manufacturers and recyclers in all countries'.

Recommendations

Five broad parameters were identified by Widmer *et al.* (2005) as essential in designing an effective WEEE management system. These include: legal regulation, system coverage, system financing, producer responsibility, and ensuring effective compliance.

There is an urgent need for the developing countries to introduce legislation dealing specifically with e-waste (Hicks *et al.* 2005, Osibanjo & Nnorom 2007). This legislation should among others include the following items enshrined in draft legislation initiated by the National Development and Reform Commission (NDRC) aimed at determining the most suitable model for the Chinese WEEE management system (Hicks *et al.* 2005).

1. The establishment of a special fund to assist in the financing of WEEE recycling and disposal.
2. The use of positive measures to encourage the establishment of WEEE recycling and disposal enterprises, as well as support the development of relevant technology, methods and education.

3. The implementation of 'extended producer responsibility' obliging producers to cover the cost of collection, recycling and disposal. Their responsibility will include using designs beneficial to recycling, choosing non-toxic, non-hazardous substances and recyclable materials and providing information to aid recycling. Appliance retailer and service provider will also be obliged to collect WEEE from consumers.

To overcome this, there is need to introduce formal recycling businesses with state-of-the-art recycling facilities in the developing countries. Such a facility will have a major impact on recycling efficiency, in terms of elements and value that are recovered as well as in terms of toxic control and overall environmental performance. Such a facility in Belgium (Umicore) treats over 250 000 tons of feed materials annually and has a capacity to recover over 100 tons of gold and 2400 tons of silver (Hageluken 2005, 2006b).

To effectively articulate and implement appropriate end-of-life management of e-waste, there must be an effective collection or take-back of the WEEE. The implementation of this will be most difficult in countries where there is no stringent enforcement of regulations on municipal solid waste management, no existing environmental protection tradition, nor efficient recycling facilities, and a high proportion of uninformed population who are unaware of the dangers of inappropriate management of waste. Unfortunately, these are the prevailing situations in most developing countries.

Conclusion

Unlike many traditional wastes, the main environmental impacts of e-waste mainly arise due to inappropriate processing, rather than inherent toxic contents, and furthermore, drawing boundaries between secondary goods intended for reuse and waste materials is difficult. There are social benefits to secondary markets, especially computers, as they make goods available to low- income people, raising standards of living. Given that unregulated processing in developing countries generate income, there is a strong economic force driving the creation of an informal sector, which poses a challenge for enforcement of regulations (Williams 2005). There is a need to introduce a system for the labelling of secondhand electronics to distinguish such from e-scrap meant for material recovery (recycling). This will ensure a certification and confirmation of the functionality of secondhand electronics meant for export. For effective management of e-waste in the developing countries, there is urgent need for the implementation of legislation dealing specifically with e-waste, the implementation of producer responsibility and the introduction of formal recycling, and appropriate landfill technology for toxic wastes that will arise from these waste management activities.

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