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Review

Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries

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Abstract

The developing countries are facing huge challenges in the management of electronic waste (e-waste) which are either internally generated or imported illegally as 'used' goods in an attempt to bridge the so-called 'digital divide'. E-waste contains hazardous constituents that may negatively impact the environment and affect human health if not properly managed. In these countries, because of lack of adequate infrastructure to manage wastes safely, these wastes are buried, burnt in the open air or dumped into surface water bodies. Crude 'backyard' recycling practices, which are not efficient and are highly polluting are also used in material recovery activities. Most developed countries have in place legislation mandating electronic manufacturers and importers to take-back used electronic products at their end-of-life (EoL) based on the principle of extended producer responsibility (EPR). In this paper, we review the concept of EPR, and discuss selected frameworks. The aim has been to find a mid point for the implementation of even an 'abridged' form of EPR in the developing countries. Implementation of EPR in the developing countries has become necessary in the light of the present high level of trans-boundary movement of e-waste into the developing countries and the lack of basic or state-of-the-art recycling and waste disposal facilities. Change in attitude by governments, appropriate legislation dealing specifically with e-waste, control of electronic waste dumping, implementation of EPR and transfer of technology on sound recycling of e-waste are the key issues in effective management of e-waste in developing countries.

Keywords: Extended producer responsibility; e-waste; Developing countries; Product take-back

Contents

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1. Introduction

The useful life of consumer electronic products is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities (Kang and Schoenung, 2004). Again the growing importance of ICT to the world economy has brought about a surge in demand for electronic equipment (Macauley et al., 2001). Waste from electrical and electronic equipment, EEE (WEEE) is one of the priority streams in waste management because of its major challenges. It has in fact become an issue of concern to solid waste management professionals (Musson et al., 2000). Challenges faced by WEEE management are not only consequences of growing quantities of waste but also the complexity of WEEE; it is one of the most complex waste streams because of the wide variety of products from mechanical devices to highly integrated systems and the accelerating technological innovations (Yla-Mella et al., 2004). As a result of the variety of product models, size changes, compatibility issues, etc., the recovery of WEEE is very challenging (Kumar et al., 2005).

In the last two decades, there has been an increase in the number of environmental policies and legislations focusing on the product development process with a view to reducing the environmental impacts resulting from the products; throughout their entire lifecycle-from product design, manufacture, through to consumption and eventual end-of-life (EoL) management. These policies and legislations are almost all based on the principles of extended producer responsibility (EPR). The EPR concept has become an established principle of environmental policy in many countries. EPR is a method of integrating sustainable development principles into international trade based on an international environmental law principle known as the "Polluter Pays Principle" (Kibert, 2004).

Increasingly, countries in Europe and Asia (Japan, Taiwan, etc.) are putting in place "take-back" laws that require that the manufacturer take-back the used products at its "end-of-life". Currently, most attention is focused on brown goods (computer, mobile phones, etc.), white goods (refrigerators, air conditioners, etc.), automobiles and batteries which require special handling and treatment (Widmer et al., 2005; Langrova, 2002). Similar legislations are either in place or under consideration at State level in the United States, particularly in California and Massachusetts (Gutowski et al., 2005).

The European Union has instituted policies such as the Waste Electrical Electronic Equipment, WEEE (Directive 2002/96/EC) and the Restriction of Hazardous Substances RoHS, (Directive 2002/96/EC) Directives, aimed at improving the environmental performance of electronic products. To address the requirement of these Directives, companies in Europe have made significant innovations to eliminate or move toward zero material waste in the products' life cycle. These innovations, driven by sustainability/environmental considerations, appear to have much broader impacts; regardless of the innovation driver, innovations will result in better products and processes that are more competitive in the global market place (Kumar et al., 2005). Traditionally, in the EU (and elsewhere), the legislative approach toward environmental problems has been one of 'command and control', largely addressing 'end-of-pipe' pollution problems (Bailey, 2002; Darby and Obara, 2005). Now, the emphasis is changing towards producer responsibility whereby those who produce goods are then responsible for the environmental impacts throughout the whole of their life cycle, from resource extraction to recycling, reuse and disposal. Unfortunately, most developing countries are yet catch up with this innovation in waste management.

The developing countries are facing huge challenges in the management of WEEE which are either internally generated or imported illegally as 'used' goods in an attempt to bridge the so-called 'digital divide'. This paper reviews the concept of EPR, and discusses selected frameworks of EPR implementation in WEEE management around the world. Implementation of EPR in the developing countries has become necessary in the light of the present high level of trans-boundary movement of WEEE into the developing countries and the absence of basic or state-of-the-art facilities for sound end-of-life material/energy recovery and disposal of WEEE.

2. Extended producer responsibility

Van Rossem et al. (2006) observed that the emergence of the EPR concept reflected several general trends in environmental policy-making. These trends are the prioritization of *preventive* measures over end-of-pipe approaches, enhancement of *lifecycle thinking* and a shift from the "command-and-control" approach to a non-prescriptive, goal-oriented approach. It aims to incorporate *incentive mechanisms* for industries to continuously improve their products and process'.

The policy instruments that lie under EPR umbrella include different types of product fees and taxes, such as, advance recycling fees (ARFs), product take-back mandates, virgin material taxes, and combinations of these instruments. Other policies include pay-as-you-throw, waste collection charges, and landfill bans. Oh and Thompson (2006) noted that a cost-effective instrument is one that exploits all the possible avenues for waste reduction, i.e., source reduction, recycling, material substitution, and product design changes, and not just a single method. Essentially, EPR is an indirect European Commission legislative-based policy designed to ensure that market pressures are harnessed to achieve environmental protection through the management of EoL EEE (Hume et al., 2002).

2.1. Theory and practice

The Organization for Economic Cooperation and Development (OECD) defined EPR as

> "an environmental policy approach in which a producers' responsibility for a product is extended to the post-consumer stage of a products life cycle including its final disposal" (OECD, 2001; Widmer et al., 2005; Walls, 2006).

EPR has also been defined by Lindhqvist (2000) as

> ". . . a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the products lifecycle, and especially to the take-back, recovery, and final disposal of the product" (Lindhqvist, 2000 cited in Van Rossem et al., 2006).

The EPR shifts responsibility- either financial or physical-upstream to the producers (Walls, 2006), and is intended to "provide incentives to producers to incorporate environmental considerations in the design of their products (Walls, 2006; OECD, 2001; Widmer et al., 2005). While there are many definitions of EPR, it is generally described as a pollution prevention policy that focuses on product systems rather than production facilities. Thus responsibility for the product is broadened beyond the emissions and effluents generated by the extraction or manufacturing processes to the management of the product once it is discarded so as to reduce waste volumes and management costs (Milojkovic and Litovski, 2005).

Economics may not encourage EoL products to be seen as assets, so legislation is needed to force take-back (Castell et al., 2004). For the producer this means that their responsibility as the product producer is extended from considering the environmental impacts generated at the production facility to those associated with all phases of the product life cycle, in particular product consumption and end-of-life (Maxwell, 2001). Due to environmental concerns, the EPR legislation are enunciated so as to hold the original supply chain players (manufacturers, importers, retailers, etc.) responsible for the collection and recovery of end-of-life (EoL) items (Krikke et al., 2003). Manufacturers have usually focused on the quality of a product and the cost. The environmental issues in a company have been regarded as only an 'end-of-pipe' treatment to comply with the environmental regulations. However, environmental concerns about a product gradually become another driving force in business activity as EPR and environmental labeling (Kim et al., 2001).

EPR was first instituted in Germany in 1991 by the passage of the "Ordinance on Avoidance of Packaging Waste" (Kibert, 2004). EPR aims at motivating manufacturers to 'design out' environmental problems as much as possible at source, i.e. at product design so as to lower the cost of waste management. An example is to design a product to be energy efficient during use, to generate less waste and especially hazardous waste at EoL and which facilitates its recovery, reuse and recycling (Maxwell, 2001). In EPR, the original equipment manufacturers (OEMs) outsource the recycling and the overall deficit is charged to the consumer when buying a new product (Krikke et al., 2003).

The EPR policy is based on the "polluter-pay principle" and is characterized by the shifting of responsibility away from the municipalities' to include the costs of treatment and disposal into the price of the product, reflecting the environmental impacts of the product (Widmer et al., 2005). The EPR policy is considered by OECD as well as the EU as one of the most promising means to combat the increasing generation of waste and pollution. It has been recognized as a concept which changes a balance of responsibility among the actors of a products' life cycle with a special attention to the end of a products' life (Langrova, 2002). The main goals of EPR are:

- waste prevention and reduction;
- product reuse;
- increased use of recycled materials in production;
- reduced natural resource consumption;
- internalization of environmental costs into product prices; and,
- energy recovery when incineration is considered appropriate (Langrova, 2002).

The EPR policy is implemented through administrative, economic and informative policy instruments (Table 1). The above policy instruments as discussed by Langrova (2002) and Lindhqvist (2000) have been adopted to prevent environmental degradation thereby combating pollution, generation of waste and conserving natural resources. These changes would include improving product recyclability and reusability, reducing material usage, downsizing products, and engaging in a host of other 'design for environment' (DfE) activities (Walls, 2006). Protection of the environment has been recognized as one of the greatest challenges facing the World today. Policy instruments

Table 1
Policy instruments used in the implementation of EPR

Administrative instruments	Collection and/or take-back of discarded products, reuse and recycling targets, setting emission limits, recovery obligation, product standards technical standards
Economic instruments	Material/product taxes, subsidies, advance disposal fee systems, deposit-refund systems, upstream combined tax/subsidies
Informative instruments	Environmental reports, environmental labeling, information provision to recyclers about the structure and substances used in products, consultation with authorities about collection network

Adapted from: Langrova (2002) and Van Rossem et al. (2006).

used to achieve these objectives as discussed by Langrova (2002) are given in Table 1.

The Netherlands was the first country in Europe to adopt and fully implement take-back legislation. The Dutch “system approach” or take-back approach has a scheme for assigning costs, relies on national system of collection points, and employs profit-oriented establishments to disassemble and process EoL products (Gutowski et al., 2005).

2.2. Types and approaches

There is a range of instrumental approaches for implementing EPR. The possible approaches and their examples as identified by the OECD are given in Table 2. A summary of these approaches as discussed by Widmer et al. (2005) and Walls (2006) are given below.

2.2.1. Mandated product take-back

With this policy approach, the government mandates that manufacturers, importers and/or retailer take-back products at the end of the products useful life. Mandated product take-back is usually combined with some kind of recycling or waste diversion target. For example, the government may require that each producer meet a recycling rate goal of say, 75% for its products (Walls, 2006). To meet these requirements, the ‘producers’ often form a “producer responsibility organization, PRO”. PROs are often instituted as a cooperative industry effort to collectively shoulder the responsibility of its member companies to meet their EPR obligations (Widmer et al., 2005; Walls, 2006).

Table 2
Possible approaches to EPR and examples

Type of EPR approach	Example
Product take-back programs	*Mandatory take-back *Voluntary or negotiated take-back programs
Regulatory approaches	*Minimum product standards *Prohibition of certain hazardous materials or products *Disposal bans, *mandated recycling
Voluntary industry practices	*Voluntary codes of products *Public/private partnership *Leasing and “servicing”, *labeling
Economic instrument	*Deposit-refund schemes *Advance recycling fees, *Fees on disposal *Material taxes/subsidies

Source: OECD (2001) cited in Widmer et al. (2005).

2.2.2. Voluntary product take-back

In this approach, the producers agree to organize a take-back system for their products and set recycling goals. In this scenario, there are no laws or government regulations mandating compliance and no penalties for not meeting the goals (Walls, 2006). The voluntary approaches are the preferred form of implementing EPR strategies, mainly to avoid the promulgation of national regulations (Widmer et al., 2005).

2.2.3. Economic instruments

Other economic instruments/approaches to EPR include advance recycling fee (ARF) or advance disposal fee (ADF), and deposit-refund schemes. ARF or ADF is a tax assessed on product sales and often used to cover the cost of recycling or disposal of products at their EoL. ARFs are often assessed per unit of the product sold but can also be assessed on a weight basis (Walls, 2006). This can also be based on the potential toxicity of the product.

2.3. Reasons for take-back of WEEE

The reasons behind products take-back can be grouped into *economic* and *ecological* concerns. A primary concern is that such equipment can contain hazardous materials, such as heavy metals and organic pollutants that could be released into the environment during incineration or concentrated and then dispersed in incinerator ash. For example, the composition of the cathode ray tube of computers (and televisions) indicates high lead contents which require special treatment (Tables 3 and 4).

Table 3
Composition of different kinds of CRT glass

Item	Composition	Basic function
Panel	0–4% lead oxide alkaline/alkaline earth aluminosilicate	Optical quality glass; X-ray attenuation; color and tint control
Funnel	22–28% lead oxide alkaline/alkaline earth aluminosilicate	High X-ray resistance; viscosity control
Neck	30% lead oxide alkaline/alkaline earth aluminosilicate	Thermal expansion match to funnel composition; X-ray absorption
Stem	29% lead oxide alkaline aluminosilicate	Expansion match to metal wire feed throughs; X-ray absorption
Gun mount	Potassium aluminosilicate sintering	Crystallization
Frit	70–80% lead oxide zinc borate	Low temperature

Source: Lee et al., 2000.

Table 4
Lead content in various CRT glass components by mass

Glass	Color CRT (%)	Monochrome CRT (%)
Panel	0–3	0–3
Funnel	24	4
Neck	30	30
Frit	70	N/A

Source: cited in Musson et al. (2000).

The hazardous content of EEE is a major concern. Every computer, including the monitor, on average contains between 1 and 2 kg of lead (20% of the weight of monitor is lead). Thus an estimated 340,000 tonnes of lead can be extracted from the 315 million computers that became obsolete in the United States between 1997 and 2004 (Milojkovic and Litovski, 2005). The hazardous materials (i.e. phosphor coatings of cathode ray tube (CRT), high-lead content in the CRT funnel glass, batteries, printed circuit boards (PCB), capacitors, mercury-containing parts, and plastics containing flame-retardant bromine, etc.) contained in waste electronic devices may seriously pollute the environment if they are not properly managed (Lee et al., 2004).

Darby and Obara (2005) observed that more than 90% of WEEE is landfilled, incinerated or recovered in the UK without any pre-treatment. As a result, the electronic industry has come under mounting pressure to reduce the impact of its products on the environment. Ecologically, product take-back will reduce the amount of toxic material such as Pb, Hg, Cd, Cr (VI), and brominated flame retardants going into the environment by introducing incentives that will help manufacturers to eliminate/reduce the amounts of these materials in the EEE at the design and manufacturing stages. In addition to the hazardous materials, some valuable materials (i.e., copper-containing motors, plastic or iron parts, gold-,silver- and copper-bearing printed circuit boards, etc.) contained in e-waste make them worth being recycled (Lee et al., 2004). There is a need to encourage sound recycling of WEEE both in the developed and developing countries considering that there is significant energy saving from using recycled materials, Table 5 (Cui and Forssberg, 2003).

Lindhqvist and Lifset (2003) observed that "although there are real reasons for improving an often well organized and appropriate collection and treatment of WEEE, it is not difficult to agree on the strategic importance of being able to influence the design process in order to have products that are formed to minimize the environmental impacts and, in particular to be easily dismantled, reused, and recycled".

Table 5
Recycled material energy savings over virgin materials

Material	Energy savings (%)
Aluminum	95
Copper	85
Iron and steel	74
Lead	65
Zinc	60
Paper	64
Plastic	>80

Source: Cui and Forssberg (2003).

As a result the effective management of EoL WEEE has become an important social and business activity that encompasses take-back, dismantling, recycling, reuse and sound management of toxic material from EEE. Properly designed recycling systems should create strong incentives for manufacturers to redesign their products. One scheme implemented by the Dutch charges manufacturers for recycling based upon the weight and a percentage share of the recycling cost attributed to the company's product. Hence lighter-weight, longer-lasting, and easier-to-disassemble products should all result in lower fees for the manufacturer (Gutowski et al., 2005).

2.4. Models/types of EPR

EPR has been recognized as a concept which changes the balance of responsibility among the actors of a product's life cycle with a special attention to the end of a product's life. The ultimate goal of EPR is sustainable development through environmentally responsible product development and product recovery (Milojkovic and Litovski, 2005). The models of EPR expounded by Lindhqvist (2000) and discussed extensively in literature are outlined below (Lindhqvist, 2000; Langrova, 2002; Milojkovic and Litovski, 2005; Oh and Thompson, 2006):

- Liability – this refers to the responsibility for proven environmental damages caused by the product in question. The extent of the liability is determined by legislation and may embrace different parts of the life cycle of the product, including usage and final disposal. The producer is thus responsible for the environmental damage caused by the product in question.
- Economic responsibility – this means that the producer will cover all or part of the expenses, for example, for the collection, recycling or final disposal of the products he is manufacturing. These expenses could be paid directly by the producer or by a special fee.
- Physical responsibility – the manufacturer is involved in the physical management of the products and/or their effects. This can range from merely developing the necessary technology, to managing the total "take-back" system for collecting and management/disposal of the products
- Ownership – the manufacturer may also retain the ownership of his products throughout their life cycle, and consequently be linked to the environmental problems of the product. In this case, the producer assumes both physical and economic responsibility. In this scenario, the product appears to be leased by the consumer, in which the consumers purchase the 'use' of the product.
- Informative responsibility – the producer is responsible for providing information about the product or its effects at the various stages of its life cycle. That is the producer will provide information on components or material list to reduce the cost of third-party involvement in post-consumer recycling.

Designing an EPR system with clear and well-defined roles is essential for all actors-producers, users, authorities, and waste managers. Issues in designing an effective WEEE management system have been identified and discussed by Widmer et al. (2005). These issues were grouped into five parameters:

1. legal regulation;
2. system coverage;
3. system financing;
4. producer responsibility;
5. ensuring compliance.

2.5. Components of an EPR

The role of EPR in the management of WEEE in the US, Europe and Asia have been discussed (Fishbein, 2002). Fishbein (2002) defined an effective EPR program as one that:

- Focuses specifically on the waste generated by end-of-life products.
- Clearly defines what financial responsibility producers have for the collection, transport, and recycling of their products at EoL.
- Sets meaningful targets for collection and recycling.
- Differentiates recycling from technologies such as waste-to-energy conversion.
- Includes reporting requirements and enforcement mechanism.
- Provides producers with incentives to design for reuse/recycling.
- Provides consumers with incentives to return their used products.

2.6. Individual vs. collective producer responsibility

The various implementations of EPR systems are capable of bringing together considerable financial resources for organizing elaborate recycling systems and is well illustrated by existing systems for products such as packaging, batteries, and vehicle (Lindhqvist and Lifset, 2003). A key issue in EPR design and implementation is whether the producer responsibility should be individual or collective. When producers have individual responsibility they pay specifically for the recycling of their own brand products; with collective responsibility, all producers jointly share the costs of managing all their waste products.

For many years now, it has been argued that in order to effectively promote design improvements, a system that allocates individual responsibility for producers is needed, as opposed to a system that requires that producers reach the set goals together, a so-called collective system. The argument is that in collective systems, the advantages from investments in product improvements will not be given only to the company investing, but will be shared, and diluted, among the full group of producers (Lindhqvist and Lifset, 2003). For example, if a company must pay to recycle its own products, it will benefit from product designs that are easier and cheaper to recycle, but if all companies pay the same fee (based on their market share) to recycle a product, there will be no incentive to make the product more recyclable.

While collective responsibility provides a funding mechanism but no incentives for companies to design for recycling, individual responsibility does provide such incentives. However, individual responsibility also entails some sorting or tracking of used products, which can be costly (Fishbein, 2002). Raymond (2002) observed that individual take-back is not practical because of the economies of scale needed, and because manufacturers will be responsible for “orphan” wastes (products that outlast their manufacturers), which must be financed collectively. Moreover, individual take-back is not feasible for small firms and imports.

Fishbein (2002) observed that although the terms individual and collective responsibility have not been well defined, the distinction between them hinges on whether the system will reward companies that “do the right thing” by designing less wasteful, more recyclable products and developing economical recycling strategies. In the development of the EU WEEE and RoHS Directives, many of the major manufacturers of EEE including Electrolux, IBM and Sony (from the three major global EEE manufacturing regions: EU, US, and Asia) and others such as HP, Nokia and Ericsson supported individual responsibility (Lindhqvist and Lifset, 2003; Fishbein, 2002). They advocated a system in which “the individual manufacturer has as much control over the take-back cost of its products as possible” (Fishbein, 2002).

Individual responsibility does not preclude producers from working together to collect, transport, and recycle used products. They can set up joint programs under this model, but individual responsibility would require that the fees they pay be based on the cost of recycling their own products (Fishbein, 2002). With implementation of the EU WEEE Directive in Europe, Darby and Obara (2005) noted that in the UK, it is likely that the collection of WEEE will be carried out by local authorities and the distributors, and producers will then provide for the financing of the dismantling and recycling of products once they are in collection facilities. They however observed that some manufacturers/producers of EEE (e.g. Electrolux, Braun, HP, and Sony) have opted for the individual responsibility approach where they will be responsible for the collection and treatment of their own products, but are working collectively to reach their WEEE obligation. The EU WEEE Directive is based on individual responsibility (Lindhqvist and Lifset, 2003).

3. EPR and sustainable development

With new technology leading to new and better products for consumers and industry, comes new challenges associated with the life cycle management of these products. At each life cycle stage, acquisition of material and energy feedstocks, product manufacture, use, maintenance, repair, and final resource recovery and disposal of waste, consideration must be given to achieving an acceptable balance between environmental impacts, economic growth, and social benefits (Fisher et al., 2005). Sustainable development has been a guiding principle for the international community since the 1992 Earth Summit in Rio de Janeiro, Brazil. EPR is a valuable tool for achieving sustainable development because it creates economic, environmental and social benefits (Kibert, 2004). Countries around the world, especially in Western Europe and Japan, recognize that a concerted effort is needed to meet the global challenges of sustainability. In order to address this challenge, greater attention has been paid to the development of energy/material efficient technologies/products, low impact manufacturing (value creation) processes, and end-of-use (value recovery) operations (Kumar et al., 2005).

The interdependence of economic, environmental and social factor as a triangular relationship has long been recognized. The first clear enunciation of this interdependence came as the result of a report commissioned by the United Nations Commission on Economic Development (UNCED); both known as the "Brundtland Report" and "Our Common Future". This report defined the term "Sustainable Development" as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Kibert, 2004). Similarly, the OECD defined sustainable development as "*the consumption of goods and services that meet basic needs and quality of life without jeopardizing the needs of future generations*" (OECD, 2002 cited in Cooper, 2005).

Increasingly, efforts are being made to look at solid waste and resource management discussion through the lens of sustainable development. This is a very challenging task but one that should help to avoid costly mistakes. Today, as manufacture, recovery, and reuse of EEE becomes a high profile issue, it is becoming more and more important to appropriately define system boundaries, embrace life cycle thinking, and apply the three principles of sustainable development, namely, ecological balance, economic growth and social progress. (Fisher et al., 2005). In order to achieve *sustainable development*, there is a need for the implementation of *sustainable consumption*. WEEE Directive represents one part of the moves within the EU towards sustainable resource and waste management practice and more responsible behavior by producers and consumers.

The literature on sustainable development increasingly recognizes a need to address resource throughput, but rarely is mention made of the potential role of product life span in slowing it down. Increased longevity could be achieved by greater intrinsic product durability and by improved maintenance through careful use, repair, upgrading, and reuse ("product life extension") (Cooper, 2005). Cooper (2005) proposed that greater attention should be paid to product life spans in order to make adequate progress toward sustainable consumption.

> Kumar et al. (2005) observed that *"to achieve sustainable (closed-loop) product and material flow cycles within an industrial ecosystem, attention must be directed at designing products for multi-use life, e.g. product, subassembly, component remanufacture and reuse, and as a last resort, material recycling. Material recycling, though not a preferred approach, will be required to recover "waste" materials in the product and process them into "new" raw materials; zero waste materials will be the goal of this approach"*.

Tackling the WEEE problem is just one small but important part of the move towards sustainability and more sustainable waste and resource management in Europe. This has indeed been successful. There is therefore a need to extend this great initiative to the developing countries. The implementation of the WEEE Directive raises awareness of issues surrounding the manufacture, use and disposal of EEE and, together with other ongoing initiatives to address general waste and encourage recycling will contribute to meeting sustainable goals (Darby and Obara, 2005). Sustainable development has been an issue of global magnitude. Since the United Nations Conference on Environment and Development also known as the Earth Summit in 1992, there have been other international declarations based on sustainable development. Of particular interest is the World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa from August 26–September 4, 2002. Yet issues and policies towards achieving sustainability are yet to be adopted or effectively implemented in most developing countries.

4. WEEE management initiatives

There have been various attempts at managing WEEE. Initiatives put in place for effective management of WEEE can be grouped into:

- voluntary private initiatives,
- state/regional initiatives, and
- global initiatives.

As at 2002, there were ten countries with "mandatory" electronic recovery laws – Belgium, Denmark, Italy, Netherlands, Norway, Sweden, Switzerland, Portugal, Japan, and Taiwan. Within the same period there were also extensive voluntary programs in a number of other countries, such as Germany, and draft take-back bill in several others. Raymond (2002) predicted that with the enforcement of the EU WEEE Directive, there will be electronic take-back mandates in nearly thirty countries by 2007. An attempt is made to briefly review selected examples of the above initiatives.

4.1. Voluntary private initiatives

There have been a number of voluntary take-back programs for WEEE components in the developed and developing countries. In the US, growing public and government attention to the problems posed by e-waste has prompted a few manufacturers and retailers to announce plans for small-scale take-back programs. Dell, Hewlett Packard (HP), International Business Machines (IBM), and other market leaders all have programs of one type or another, mostly focused on their customers/products. But none claims to receive or recycle more than 10% of their annual sales (Milojkovic and Litovski, 2005).

In China, mobile phone producers have a program to collect waste phones and accessories. Nokia launched its "Future is in Your Hand" campaign in the Asia-Pacific in 2001, and in China in 2002, with more than 200 recycling bins placed in around 100 major cities at Nokia service centers (Hicks et al., 2005). One hindrance to such private initiatives is the unwillingness of consumers to handout their EoL EEE. Hicks et al. (2005) observed that Nokia China collected approximately 0.5 tonnes of batteries and chargers, as consumers prefer to sell old mobile phones in the second-hand market, a common practice in China and other developing countries (Hicks et al., 2005). Similar programs by Philips and Motorola are also ongoing in China and other Asia-Pacific countries. Private firms such as Citraya of Singapore are also investing heavily in WEEE recycling (Hicks et al., 2005).

The European Recycling Platform (ERP) established in 2002 by Hewlett Packard, Sony, Braun and Electrolux is another private initiative aimed at enabling producers to comply with the EU WEEE Directive. It aims to evaluate, plan and operate a pan-European platform for recycling and waste management services. There have been a number of voluntary take-back programs for cell phones in Europe. The most notable of these was carried out by the Cellular Phones Take-Back Working Group of the European Electronics Industry (ECTEL). In this pilot project, the participating companies (Alcatel, Ericsson, Motorola, Nokia, Panasonic, and Philips) took back their own phones in the UK and Sweden during 1997 (Fishbein, 2002). Even before the EU WEEE Directive became effective, the 'Remarking and Recycling Center' of Fujitsu Siemens Computers GmbH (FSC) in Paderborn, Germany was in operation, and is presently processing about 3500–4000 tonnes of end-of-use IT products annually (Kanzawa and Takahashi, 2005).

4.2. State/regional initiatives

4.2.1. European union: the WEEE Directive

The European Union Waste Electrical Electronics Directive (Directive 2002/96/EC) is part of a shift in environmental legislation from processes to products that began in the early 1990s. This was as a result of the upward trend in waste generation which must be halted and reversed in terms of both volumes and environmental hazard and damage (Castell et al., 2004). The EU Commission had proposed the Directive in June 2000 after launching consultation on the proposal in 1997. The initial idea goes back to a proposal of Klaus Töpfer in 1991, who at that time had been the German minister for environment (Hageluken, 2006). In April 2001, the European Commission (EC) submitted the "Directive on Waste from Electrical and Electronic Equipment" to the European Parliament. Among its many articles, this proposal calls on EU member states to require distributors and manufacturers to take-back EEE and sets ambitious recycling rate goals for WEEE (Macauley et al., 2001).

The EU had in 1991 designated e-waste as a priority waste stream and in August 2004, the legislation on Waste from EEE (WEEE) came into force, making it incumbent on manufacturers and distributors in EU member states to take-back their products from consumers and recycle them. The WEEE Directive focuses on EPR, linking product disposal to design as a driver for eco-design (Castell et al., 2004). Article 1 of the WEEE Directive states that: "the purpose of this Directive is, as a first priority, the prevention of waste electrical and electronic equipment (WEEE) and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste". The WEEE Directive describes ten (10) categories of WEEE (Table 6) and covers EEE used both by consumers and professionals.

Table 6
WEEE categories according to the EU WEEE Directive

WEEE Category	Label
1. Large household appliances	Large HH
2. Small household appliances	Small HH
3. IT and telecommunication equipment	ICT
4. Consumer equipment	CE
5. Lighting equipment	Lighting
6. Electrical and electronic tools[a]	E & E tools
7. Toys, leisure and spots equipment	Toys
8. Medical devices[b]	Medical equipment
9. Monitoring and control instruments	M & C
10. Automatic dispensers	Dispensers

Source: Antrekowitsch et al. (2006), Widmer et al. (2005).
[a] With the exception of large-scale stationary industrial tools.
[b] With the exception of all implanted and infected products.

The objectives of the WEEE Directive are to divert e-waste from landfill and incinerators to environmentally sound reuse and recycling, to preserve resources, in particular energy, and to harmonize national measures on the management of WEEE. The responsibility for organizing collection of WEEE and financing its recycling has to be taken over by the producers of EEE (Hageluken, 2006). The Directive stipulates the following:

- The design and production of EEE should facilitate dismantling and recovery for later reuse and recycling of the WEEE.
- WEEE should be collected separately from other forms of waste, and this collection should be free of charge to households.
- Best available treatment, recovery and recycling techniques should be used to ensure health and environmental protection.
- EEE put on the market after 13 August 2005 must be labeled with the 'wheelie bin' graphic in order to keep the product out of general municipal waste collection.
- By the end of 2006, member states must meet a rate of 4 kg/year/inhabitant collected from private households.
- By the end of 2006, producers must meet a target of reuse and recycling for the WEEE that they receive. The target rate varies from 50 to 80% per category of WEEE (Table 7).
- Producers are responsible for financing the take-back and management of WEEE.
- Information necessary to fulfill these requirements should be provided to users and to treatment facilities.

Table 7
Targets per group/category of WEEE Categories

WEEE type	Category	Recovery[a] (%)	Reuse/recycling[b] (%)
Large HH	1; 10	80	75
ICT	3; 4	75	65
Gas discharge lamps	(5)	80	80
Others	2; 5; 6; 7; 9	70	50

Source: Hageluken (2005).
[a] Recovery by weight.
[b] Component material and substance reuse and recycle by weight required.

- Both producer and member states must report the result of their compliance with the Directive to the EU at regular periods as defined by each member state (Dickenson, 2006).

Gutowski et al. (2005) observed that European manufacturers no longer question the issue of product take-back, but rather are focusing their energies on how to achieve the best results.

4.2.2. Finland

In Finland, the technology industries introduced the AWARENESS (Advanced WEEE Recovery and Recycling Management System) Project in summer 2003 which focuses on influences of the WEEE Directive on manufacturers and producers of EEE. The goal of the project is to support companies in arriving at a consensus on WEEE Directive implementation details. In addition, the project aims to initiate company co-operation in different product categories and to take optimal recycling processes into use. The AWARENESS project consists of two sub-projects called SELMA and RecISys. SELMA focuses on managing issues related to operational recycling and carrying out communication between national authorities and companies. The main objective of the ReclSys is to develop the internet-based information system, which will meet the information needs of WEEE and RoHS Directives. Controlling the operation of recycling processes, reporting to the authorities as well as informing customers and the recycling industry will be done through this information system.

In the Finnish system, offices or institutions can contact the companies participating in WEEE recovery business to remove and take their equipment to designated reception places. Most electronic goods retailers also take-back old equipment in association with buying a new one. Regional waste management companies also receive electronic wastes. Most of the time, a discard fee has to be paid and this varies from 1 to 36 euros (€) depending on the category of the equipment.

Yla-Mella et al. (2004) reviewed electrical and electronic product take-back and recycling activities in Finland and observed that there are several WEEE operators in the recovery business but only few treat the collected items for recovery. The WEEE is usually collected and pre-treated by some operators before transportation elsewhere for the actual treatment and material utilization.

4.2.3. Japan

EPR has developed quite differently in Japan than in Europe. In particular, take-back does not have to be free – consumers pay when they bring used equipment back to retailers. Producers set the take-back fees for their own products (Fishbein, 2002). Japan established a take-back system for four types of e-waste (air conditioners, TVs, refrigerators and washing machines) in 1998. In order to implement the taking back system, the ministries and authorities concerned mandated all producers of electronic products to undertake the environmentally sound management of these categories of WEEE pursuant to the law, regulations, and guidelines. All Japanese producers of electronic products take high priority to undertake the environmentally sound management of these e-wastes not only for the protection of the environment but also for their business approach. In the Japanese system, the recycling of WEEE is a producer-specific responsibility. The law also specifies rate targets and imposes heavy penalties for non-compliance (Widmer et al., 2005).

By 2004 there were forty-one recycling facilities for e-waste in Japan. Most of the facilities are financially supported by the ministries and municipalities or Japanese producers of electronic products. Japanese producers of electronic products involve the business strategy to deal with e-waste in the environmentally sound management of e-waste and have their own facilities or collaborate with other producers to set up and operate facilities. E-waste released from households is collected by retail shops when it is discharged or consumers buy new products. The collected e-waste is transferred to the collection places (380 places) and finally transferred to facilities by distribution system (Li et al., 2004). A key feature of the Japanese system is use of primary disassembly process to remove major components prior to a chip and sort process for handling the remainder. Automation and mechanization have been introduced to ensure safe handling of large and heavy products.

EPR has had significant impact in product re-design. Japanese electronics companies were the first to develop lead free solders and other bromine free printed wiring boards in response to the EU WEEE and RoHS directives (Gutowski et al., 2005). They are also competing fiercely to design lighter and slimmer products that are cheaper and easier to recycle. They also design for disassembly, reducing the number or plastic resins in their products and reusing parts (Fishbein, 2002).

The Japanese Specified Home Appliances Recycling law or the Electric Household Appliance Recycling Law, EHARL, which has been in force since April 2001, stipulates specifically the collection, transportation and recycling mechanism of WEEE for four categories only – TVs, refrigerators, washing machines and air conditioners (Widmer et al., 2005; INFORM, 2003, 2004; Maxwell, 2001). The law requires manufactures and importers to collect and recycle their own appliances. The Association for Electric Home Appliances (AEHA), a trade group is responsible for 'orphan' products (those products that outlast their manufacturers).

A similar legislation is now in place for the collection and recycling of used computers in Japan since 2003. The revised recycling promotion law in Japan creates two different structures for used computers. For those purchased prior to October 1, 2003, recycling is financed by EoL fees ranging from US $27 to US $37. For personal computers purchased after October 1, 2003, the costs of recycling are included in the price of the product as an advance recycling fee. This new legislation also mandates manufacturers to take care of their respective products after they have been handed in by the last owners. This system is being implemented with each manufacturer being individually responsible for financing the recycling of its products, but being allowed to charge the last owner at the time of disposal (Lindhqvist and Lifset, 2003). This system is an example of individual producer responsibility since the producers have both physical and financial responsibility for recycling their own products.

Lacking the upstream payment in the form of ADF, the Japanese system may face problems of last owners being reluctant to hand in the EoL products (Lindhqvist and Lifset, 2003; Fishbein, 2002). While consumers may be willing to pay to return a refrigerator, they may be less willing to bring back a cell phone which they can easily throw out in the trash. Consumers are notified of the ADF or recycling treatment fees when they purchase new equipment.

4.2.4. Switzerland

Legislation on e-waste management was introduced into Switzerland in 1998 when the Ordinance on ‘The Return, the Taking Back and the Disposal of Electrical and Electronic Appliances’ (ORDEA) came into force (Oh and Thompson, 2006; Sinha-Khetriwal et al., 2005; Widmer et al., 2005; Fishbein, 2002). Switzerland has two separate WEEE recycling systems operated by two Producer Responsibility Organizations (PROs); the SWICO (The Swiss Association for Information, Communication and Organizational Technology) Recycling Guarantee and the S.EN.S (Stiftung Entsorgung Schweiz) System. Along broad lines, SWICO manages ‘brown goods’- electronic equipment such as computers, TVs, radios, etc., while S.EN.S handles ‘white goods’ such as washing machines, refrigerators, ovens, etc. (Sinha-Khetriwal et al., 2005).

The SWICO Recycling Guarantee was created in 1993 by the SWICO – the association of manufacturers and importers of office electronics and IT equipment in Switzerland. When it came into force in 1994, only office electronic and IT equipment were covered. Subsequent years saw the inclusion of further categories such as mobile telephone, equipment used in the graphics industry, telephones and telephone switchboard systems, consumer electronics, as well as dental equipment (Hischier et al., 2005; Widmer et al., 2005). SWICO is a non-profit company organized by industry with over 400 member companies. Participation was originally voluntary but was mandated by a national ordinance in 1998 (Fishbein, 2002). In the Swiss system, the producers bear full responsibility of the implementation and operation, covering the entire spectrum of WEEE without being brand- or product-specific, and the entire system is financed through product based recycling fees (Widmer et al., 2005). As such the retailers, manufacturers, and importers must take-back their equipment free of charge and manage it in “an environmentally tolerable way” (Fishbein, 2002). Up until January 2002, consumers had to pay a fee to voluntary recycle their electronics through the SWICO system. From 2002, consumers were able to return their EoL electronics free of charge as the free system came into force (Raymond, 2002).

The Swiss Foundation for Waste Management (S.EN.S) was established in 1990 as a non-profit organization that operates recuperation solution on behalf of manufacturers, importers and retailers. Its initial field of activities was the recycling of refrigerators and freezers. Today, S.EN.S is responsible for household appliances, electrical tools, building, gardening and hobby appliances, electrical and electronic toys, as well as lighting equipment.

Both systems established take-back and recycling systems financed by ARF that the consumer pays when buying the respective EEE. Together with their Technical Control Bodies, they created a regulation that outlines the prerequisites for the recycling companies to be commissioned for either of the systems. Companies that satisfy these get a contract with the respective system owner to process the electronic scrap taken back by the respective system. These companies – a total of 30 companies by the end of 2004, with 14 of them having contracts with both system owners – are continuously monitored by the two independent control organizations of the respective systems of SWICO and S.EN.S. As at 2002, the overall recovery of IT equipment was estimated at 60–70% in Switzerland (Raymond, 2002). By the effort of these systems, about 75,000 tonnes of electrical and electronic devices were collected, sorted and dismantled and subsequently treated in Switzerland in 2004 (Hischier et al., 2005), while about 68,000 tonnes was collected in 2003(Sinha-Khetriwal et al., 2005). Sinha-Khetriwal et al. (2005) observed that Switzerland was the first country in the world to establish a formal system to manage e-waste.

4.2.5. Taiwan

In 1998, Taiwan accounted for 13% of the global PC production. The accumulated PC installation units increased from 1.773million in 1995 to 3.545 million in 1998 while the PC units installed per thousand of population in Taiwan also increased from 83 in 1995 to 163 in 1998 (Lee et al., 2000). Unfortunately, by 1998, there was no formal scrap computer recycling activity in the country considering that an estimated 300,000 scrap PCs are generated each year in the country (Lee et al., 2000). This was attributed to lack of consumer awareness on sound EoL management of EE products and insufficient economic incentives to encourage the establishment of a scrap computer recycling system.

In 1997, a producer responsibility recycling program for scrap computers was introduced in Taiwan mandating manufacturers and importers of computer peripherals with the later recovery and recycling of their products by March 1, 1998. Consequently, in January 1998, the Scrap Computer Management (SCM) Foundation was established to manage and implement the recycling of scrap computers in Taiwan. The main functions of the Foundation were to:

- propose scrap computer processing fee,
- identify responsible computer manufacturers and importers,
- establish a scrap processing fee collection system,
- set up the scrap computer recycling system,
- select storage and treatment facilities for scrap computer recycling,
- supervise a third party to audit scrap computer recycling work, and,
- subsidize scrap computer recycling related research projects.

The scrap computer processing fee was introduced and became effective in June 1998 and is collected from the manufacturers and importers by the SCM Foundation. The SCM

Foundation promotes scrap computer recycling by encouraging consumers to bring their scrap computer to designated collection points by offering reward money. Owing to lack of proper treatment facilities and recycling technology for recycling scrap computers, as at 1998 in Taiwan, the SCM focused only on the collection and storage of scrap computers until scrap computer treatment facilities were available. With this framework in place, between June and October 1998, a total of about 91,000 units of PC peripherals were recovered. Under the EPR program in Taiwan, the subsequent years saw the establishment of several local recycling plants to treat and recycle scrap computers (Lee et al., 2004).

4.3. Global initiatives

The foremost global initiative aimed at tackling the WEEE issues is the Basel Convention and Basel Ban. This is a global agreement, initiated in 1992, aimed at regulating the movement of hazardous wastes, including WEEE, between countries. There are some ongoing initiatives at finding solutions to the e-waste problems from a global perspective. One of these initiatives is the SteP Initiative ('solving the e-waste problem, SteP) co-initiated and coordinated by the United Nations' research arm, the United Nations University (UNU). The SteP Initiative started in 2004 at the 'Electronic Goes Green' Conference in Berlin. The Initiative is intended to build an international platform to exchange and develop knowledge on WEEE Systems among countries to enhance and coordinate various efforts around the world on the reverse supply chain (SteP, 2005 cited in Widmer et al., 2005).

SteP functions as a neutral arena of various UN organizations (e.g. UNEP, UNCTD, UNU) with prominent partners from industry, governments, civil society and the science sector. The initiative aim is to initiate dialogue and promote the development of feasible, just and sustainable solutions to the global mounting e-waste problem. The main focus of the SteP Initiative is in the following areas:

- policy,
- redesign,
- recycle,
- reuse, and
- knowledge management and capacity-building.

Through this coordinated effort, it is hoped that lessons from the EU WEEE Directive – both the good and the bad – can be addressed globally, the end result being the development of e-waste legislation that provides a worldwide solution to this mounting problem (Dickenson, 20060). Manufacturers/producers such as Fujitsu are also actively involved in private initiatives aimed at effective management of WEEE. Fujitsu is establishing a Global Recycling Network (GRN) to enable networking of its major overseas recycling systems in order to effectively handle the take-back and resource reuse of end-of-use IT products with a global perspective (Kanzawa and Takahashi, 2005).

4.4. Comparison of EPR mechanisms (mandated vs. voluntary)

In the US, implementation of EPR mechanism is voluntary by the industries whereas in the EU, the impetus comes from the government. In the US, EPR is known as extended product responsibility to emphasize that the responsibility is shared – the producer is not the only responsible party but also the packaging manufacturer, the consumer and the retailer (Kibert, 2004).

Kibert (2004) observed that there are criticisms of EPR. He observed that the 1991 German 'Ordinance on Avoidance of Packaging Waste' was criticized in three ways: (1) it was too expensive because there was not enough recycling capacity in the country so materials were shipped out of the country primarily to Asian countries where it is unknown how they were ultimately disposed of; (2) it was too ambitious because it did not address the side effects of mandatory take-back schemes; and (3) It did not address the fundamental problem of consumption. These issues have been addressed making the EPR program much more effective.

The WEEE Directive is a government EPR program that utilizes the Polluter Pays Principle and makes the producer responsible, at no cost to the consumer, for the treatment, reuse or recycling of WEEE. On the other hand in the US, the EPR program is voluntary/private. On their own companies such as IBM, HP, and Dell have started their own "take-back" programs for WEEE adding to the global market for WEEE disposal. However, the US programs differ significantly from the mandated government programs because the consumer must pay for disposal (Kibert, 2004). This also applies in the Japanese system. However the Japanese system is government-driven backed by legislation. At the other extreme is the Taiwanese system in which the consumer is encouraged to hand in their EoL products by offering reward money.

The EU WEEE Directive (Article 6) requires that materials exported outside of the EU for treatment must meet the standards set out in the WEEE Directive such as use of best available treatment (BAT) methods if they are to be counted towards the target goals for WEEE recovered. Kibert (2004) observed that "this provision is an important safeguard for ensuring that the health and environment of a foreign country is not negatively impacted by exportation of hazardous waste. The European Union's WEEE Directive actually implements sustainable development by allowing economic growth within environmental constraints". The question begging for answer is "*how does used and scrap electronic devices from European countries end up in poor developing countries that do not have even the basic waste infrastructure for management of household waste*?"

There is no mandated take-back for EoL electronics in the US. Government and the industry in the US have been looking to different collection "models" in Europe in hopes of learning how they can possibly set up an efficient national "take-back" system in the US in a voluntary basis (Raymond, 2002). The US companies' voluntary "Take-Back" programs often end up in developing countries as documented by the Basel Action Network (BAN/SVTC, 2002; BAN, 2005), the Greenpeace

(Greenpeace, 2005); and other non-governmental organizations (NGOs) such as the Toxic Dispatch. The e-wastes collected in US and sent to recyclers are eventually sold as mixed scrap to brokers who export such obsolete/scrap materials in bulk to Asia and other developing countries such as Nigeria. Kibert (2004) noted that "*disposing of WEEE without any environmental controls is unethical, especially considering that consumers pay for this waste to be safely disposed of, not dumped on the ground of a developing country*".

4.5. The scenario in developing countries

Companies from the developed countries have been known to take advantage of the absence or lax enforcement of environmental laws in the developing countries, leaving a trail of environmental destruction. Kibert (2004) noted that it is necessary to have both an international law regime, and a compatible domestic law regime, to keep multi-national corporations in compliance with environmental laws.

This has become necessary as it has been observed that "when companies from the developed countries do business with developing countries that do not have good environmental laws in place or cannot enforce such laws, "obedience" to environmental laws is ignored with the companies engaging in anti-environmental actions. As such these companies that have been "a good servant" in the West will now turn into "a poor master" in the developing countries" (Kibert, 2004). The importance of establishing a regulated WEEE management framework has been widely recognized but progress with regard to legislation, the collecting system and the construction of formal recycling facilities is slow especially in the developing countries (Liu et al., 2006). Kojima (2005) discussed the issues involved in developing a sound recycling industry in developing countries and observed that it may be difficult to apply EPR in developing countries because of the following:

1. In countries with rural communities that have low home appliance rates, used household appliances flows from cities into the countryside. Added to which, reuse is the norm and even with appliances that are beyond repair, parts are replaced and the appliances continue to be used, which makes it difficult to collect EoL equipment as is.
2. Recycling is being undertaken by the informal sector, meaning that even were responsibility for this task is assigned to producers and importers, collecting used home appliances would be no easy task.
3. It is also difficult to establish where the responsibility lies for used products that have been repaired or modified and smuggled products lies, with the producer or with the importer? This also applies to 'cloned' computer systems in which components and modules made by different manufacturers are used.
4. Where used products are being imported, there are no figures on the number of importing agents that handle such products as 'new' products, and there are believed to be innumerable importers of the products of just one brand
5. There are also products that have been brought in as private imports, and it is thus difficult to identify which product was imported by whom.

Table 8
Heavy metal levels reported in water and sediments samples at Guiyu, China

	Lianjiang (sediment)[a]	Nanyang (sediment)[a]	Lianjiang (river)[b]
Lead	230	47.3	1.9–24
	(94.3)[c]		
	79.5–590	28.6–76.9	–
Nickel	181	25.2	–
	26.0–543	12.4–39.8	–
Cadmium	4.09	NA	0.01–0.033
	ND–10.3	ND–0.57	–
Copper	1070	85.1	1.3–2.6
	(531.2)[c]		
	125–4540	17.0–346	

[a] Value in mg/kg; source: Wong et al. (2007).
[b] Values in mg/L; source BAN/SVTC (2002) cited in Hicks et al. (2005).
[c] Data from Leung et al. (2004) cited in Liu et al. (2006).

E-waste is dumped in developing countries and in Eastern Europe from Western European countries, USA, Canada and Japan (Oh and Thompson, 2006; BAN/SVTC, 2002; BAN, 2005). This is environmentally unjust and undermines the ecosystem health. Exporting e-waste to developing countries exposes these countries to hazardous waste and toxics, forcing them to choose between "poverty and poison" (BAN/SVTC, 2002). This is more so because these countries are not using the appropriate technology for waste management.

A typical example of the hazards of crude recycling of e-waste is the Guiyu town in Chaozhou region, Southeastern Guangdong province of China. This town attracted international attention after a documentary report on e-waste trading and processing in Asia by Basel Action Network (BAN) and Greenpeace in 2002. The majority of e-waste recycling in China is processed in backyards or small workshops using crude methods such as manual disassembly and open burning. In this town primitive recycling processes/techniques used include open burning of plastics (to reduce waste volume), and copper wires (to salvage valuable metals, e.g. copper), strong acid leaching of printed wiring boards, PWBs (to recover precious metals) from which the waste acid were discharged into nearby streams, and grilling of PWBs over honeycomb–coal fires to melt solder (to allow collection of electronic components, e.g. diodes and resistors) (Wong et al., 2007; Liu et al., 2006;Roman and Puckett, 2002). These operations are usually carried out with no or very little personal protection equipment or pollution control measures. As a result, high levels of human exposure to toxins and environmental pollution have been reported (Wong et al., 2007; Liu et al., 2006; Leung et al., 2004; Roman and Puckett, 2002; Greenpeace, 2005; BAN/SVTC, 2002). Table 8 give a summary of the levels of heavy metals reported in water and sediment samples from rivers within the Guiyu e-waste recycling village. Due to ground water pollution, Guiyu's drinking water has been delivered from a nearby town for over a decade now. There are also case reports of increasing respiratory tract infections, kidney stones, and the incidence of these health problems are higher among the migrant workers (Hicks et al., 2005; Liu et al., 2006). Adverse health effects on population from contact with hazardous wastes may involve any organ system, depending on the specific chemical(s) contacted, the extent of exposure, the characteristics of the exposed individual (age, sex, body weight, genetic makeup, immunological status), the metabolism of the chemical(s) involved, weather conditions, and the presence or absence of confounding variables such as other diseases (Asent-Duah et al., 1992).

The reasons behind the present low-end management of WEEE and the existence of ineffective informal WEEE processing sector in the developing countries include:

- The unwillingness of consumers to handout their EoL goods or pay for the disposal of their waste. This is because consumers view their waste as a resources and income-generating opportunity.
- There is a general reluctance to pay for waste recycling and disposal services, particularly when consumers can make money by selling their old and broken appliances.
- Emotional attachment to EEE and the attachment of perceived value on such EoL EEE.
- Uncoordinated high level of importation of e-waste as secondhand devices.
- There is a lack of awareness among consumers, collectors and recyclers of the potential hazards of WEEE.
- Lack of funds and investment to finance improvements in e-scrap recycling.
- Absence of infrastructure for the recycling or appropriate management of e-scrap following the principles of sustainable development.
- Absence or ineffective take-back programs for EoL WEEE.
- Lack of interest in e-waste management by multi-national ICT companies in the developing countries.
- Absence of legislation dealing specifically with e-waste or ineffective/lax implementation of existing regulations on the trans-boundary movement and/or e-scrap management (Osibanjo and Nnorom, 2007; Hicks et al., 2005; Finlay, 2005).

The lack of any kind of e-waste recycling in Nigeria and other African nations means that this useless imported materials ends up as the worst global examples of waste mismanagement (BAN, 2005). The BAN (2005) study in Nigeria observed that “even if Africa possessed state-of-the-art waste management systems, such disproportionate burdening of these peoples and environments in Africa with toxic wastes would be an environmental injustice”. Therefore, health risk assessments are required for the analysis of such hazardous waste sites.

5. The EU WEEE directive and the developing countries

Presently, EPR and recycling systems for WEEE are functioning effectively individually – that is at state or regional (EU) levels. With the globalization of the market economy and product outsourcing, a large number of ICT equipment are now being sold and used around the world – even at the most remote areas of the third world countries. How effective will EPR be if these products at their EoL in the developing countries are not appropriately managed? EPR should be implemented with a global perspective, in order to achieve “real” sustainable (closed loop) product and material flow cycles.

Kibert (2004) observed that government-run EPR programs, such as the EU WEEE Directive, have the potential to make sustainable development a reality considering the following provisions in the Directive:

1. The WEEE Directive creates an incentive for producer to eliminate hazardous substances from their products and to design them to be easily disassembled or reused.
2. The WEEE Directive sets up mandatory goals for the member states to reach for WEEE recovery and also requires the member states to set up a collection system.
3. The producers are financially responsible.
4. The requirements are specified for the treatment and recovery of WEEE according to category thereby encouraging technological and scientific innovation.
5. There is a provision that requires exported WEEE to meet the same requirements as EU treated WEEE in order to count toward the mandatory recovery goals.

These provisions of the EU WEEE Directive (seemingly) protects the developing countries and encourages them to use their comparative advantage of cheap labor without sacrificing the environment or the health of the population as typified by the Guiyu town in China. But are these provisions influencing e-waste exports into developing countries and e-waste management in these countries?

Kanzawa and Takahashi (2005) proposed the establishment of regional recycling systems by EEE producers that will not only function independently but also be closely coordinated and developed into a Global Recycle Network (GRN) in order to share recycling know-how and information and circulate resources and products using recycle logistics based on international values. In order to establish a GRN, Kanzawa and Takahashi (2005) proposed two steps:

- Creation of an information exchange network to mutually and effectively utilize know-how accumulated through the establishment of recycle system in various countries or regions. This will among others:
  1. improve each recycle system through mutual sharing and appropriate supply of recycle know-how and information;
  2. ensure upgrading and consistency of the products recycling information supplied to recycle partners in each area, and;
  3. create information feedback to product designers to improve recyclability.
- Establishment of a system for trans-boundary movement of resources across borders in line with existing (or new) inter-

national treaties, national laws and regulations. This will in turn ensure:

1. early exchange of information about trans-boundary movement laws and regulations for end-of-use products and resources,
2. improvement in recycle efficiency and cost reduction through recycle logistics between each area and,
3. efficient circulations of resources in each recycle system and mutual supplementation of resources among recycle systems (Kanzawa and Takahashi, 2005).

It is expected that the incentives provided by EPR will induce changes which will include: improving product recyclability and reusability, reducing material usage and downsizing products, lower energy consumption and greenhouse gas (GHG) production, reduce dependence on virgin materials, spur new business enterprises, generate new job opportunities, and provide financial savings to companies improving their design, production and distribution processes (Quinn, 2006 in Oh and Thompson, 2006).

5.1. Recommendations

There is need to establish legislations for effective WEEE management in the developing countries. The legislation should take the format of the two EU directives on WEEE and RoHS. The legislation should be in line with issues contained in a draft legislation proposed for the recycling and disposal/management of WEEE in China. The draft legislation which should be similar to the EU directives should take cognizance of the following items:

- Make provision for the adequate funding of WEEE collection, storage, and recycling and/or disposal.
- Introduce measures to encourage the establishment of WEEE recycling and disposal enterprises.
- Encourage the development of relevant and/or best available technology for WEEE management.
- Implement EPR mandating producers, importers/retailers with the cost of collecting, recycling and disposal of WEEE.
- Encourage importation and consumption of EEE that complies with the EU RoHS Directive. That is EEE designed for recycling and manufactured with non-toxic, non-hazardous substances and recyclable materials for example through tax incentives or endorsement.
- The establishment of standards and a certification system for second hand appliances, and recycling and disposal enterprises to ensure safety and the environmentally sound processing of WEEE (Hicks et al., 2005).

Our other recommendations are in line with issues contained in the proposal for 'declaration on environmentally sound management of e-waste' by the Basel Convention. Basel Convention is of the opinion that a framework for the environmentally sound management of e-waste can include principles to support traceability, predictability and transparency and could include:

1. Export of WEEE should not take place if the receiving country does not possess adequate capacity to manage these wastes in a way to protect health and the environment.
2. WEEE characterized as hazardous should be subject to control under the Basel Convention.
3. Electronic waste, whether hazardous or not, should be handled in line with environmentally sound management principles, criteria and practices.
4. Testing of used or EoL electronics and electrical equipment prior to export, to determine functionality of their hazardous component should be encouraged.

We also recommend the application of 'product life extension' for EEE through careful use of products, repair, refurbishing and remanufacturing. This can be achieved by establishing 'Remanufacturing Centers' in the developing countries where 'repair', 'refurbishing' and 'remanufacturing' activities for EEE can be carried out under the direct supervision of the OEMs or their subsidiaries and warranties issued for such remanufactured products (Nnorom et al., 2007). This could be through voluntary efforts by the OEMs or mandated through government policies. Regional recycling centers can be established through cooperation between regional bodies such as the African Union, the New Partnership for African Development (NEPAD), ECOWAS, etc. in Africa and the OEMs, and the relevant UN agencies and other international NGOs. This will be effective if WEEE related policies and legislations/treaties are made at the regional level. These activities will also create jobs and assist the local EEE industry to develop.

6. Discussion

Most developing countries, including Nigeria, do not have formal government-driven or private industry-driven EPR program for EEE management. This is worsened by the governments' attitude toward trans-boundary movement of electronic wastes into their countries and the prevailing low-end "crude" recycling activities. Governments and their officials in most developing countries appear to be far removed from the material flow and environmental implications of e-waste imports into their various countries (Osibanjo and Nnorom, 2007). Government involvement in e-waste flows and management will ensure that the developing countries are not encouraged to engage in the "race to the bottom" while participating in the global waste market (Kibert, 2004). There is therefore an urgent need for the introduction of both government-driven (mandated) and industry-driven (voluntary) EPR programs in the developing countries to check the repeat of the colossal environmental contamination at "Guiyu" e-waste recycling village in China, in other developing countries. The implementation of effective reuse of components and modules and the remanufacture of EEE will be a way forward, apart from the establishment of state-of-the-art recycling facilities.

Kibert (2004) noted that 'an assurance that developed countries' recycling and material recovery is not contributing to environmental degradation in the developing world is important to maintain consumer confidence, and consequently, economic health. Allowing the duplication of "Guiyu" in other developing countries will amount to not only an environmental injustice and rhetoric but also to fragrant abuse of the much-touted "Precautionary Principle".

For an EPR program to be effective and gain public confidence, government action is likely needed. This is because an effective EPR program has a plethora of elements many of which would be difficult for an industry group to perform while maintaining public confidence. Required EPR program elements include:

- promulgation of technical standards,
- provision of incentives to participate as well as to continually re-evaluate manufacturing processes and materials,
- dissemination of information to consumers and treatment facilities,
- maintain accountability for end products, perform, and,
- effective monitoring and program evaluation (Kibert, 2004).

For the government to maintain an EPR program with all of these elements would take a systematic commitment to sustainable development. Environmentally sound management of e-waste encompasses resource conservation and re-use, material recovery and energy efficiency. Consequently, the environmentally sound management of used or EoL EEE has to be articulated in the context of integrated waste management and life cycle approach to materials (BC, 2006).

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