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E-waste: a problem or an opportunity? Review of issues, challenges and solutions in Asian countries

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Abstract

Safe management of electronic and electrical waste (e-waste/WEEE) is becoming a major problem for many countries around the world. In particular, developing countries face a number of issues with the generation, transboundary movement and management of e-waste. It is estimated that the world generates around 20–50 million tonnes of e-waste annually, most of it from Asian countries. Improper handling of e-waste can cause harm to the environment and human health because of its toxic components. Several countries around the world are now struggling to deal with this emerging threat. Although the current emphasis is on end-of-life management of e-waste activities, such as reuse, servicing, remanufacturing, recycling and disposal, upstream reduction of e-waste generation through green design and cleaner production is gaining much attention. Environmentally sound management (ESM) of e-waste in developing countries is absent or very limited. Transboundary movement of e-waste is a major issue throughout the region. Dealing with the informal recycling sector is a complex social and environmental issue. There are significant numbers of such challenges faced by these countries in achieving ESM of e-waste. This article aims to present a review of challenges and issues faced by Asian countries in managing their e-waste in a sustainable way.

Keywords

Asian countries, EPR, e-waste, informal sector, transboundary movement, WEEE

Introduction

Electronic waste or e-waste is one of the fastest growing solid waste streams around the world today. According to the studies conducted in the European Union (EU), e-waste is growing at a rate of 3% to 5% per annum, or approximately three times faster than other individual waste streams in the solid waste sector (Schwarzer et al., 2005). Rapid uptake of information technology around the world coupled with the advent of new design and technology at regular intervals in the electronic sector is causing the early obsolescence of many electronic items used around the world today.

In the USA, where it the country is believed to produce the largest amount of e-waste in the world, it is estimated that in 2009 around 5 million tonnes of e-waste were in storage and 2.37 million tonnes of e-waste were ready for disposal, which represents an increase of around 120% from 1999 levels (United States Environmental Protection Agency, 2011). In the EU the total generation of e-waste in 2005 was estimated to be 9.3 million tonnes, which included 40 million personal computers and 32 million televisions (United Nations University, 2007a). E-waste in the fastest growing waste stream in EU and is predicted to grow to 12 million tonnes by 2020 (Computer Aid International, 2010). It is estimated that in China 83 million units of electronic and electrical equipment (EEE) were scrapped in 2007 reaching to 227 million by 2012 with an average annual growth of 19.9% (Veenstra et al., 2010). In Japan, it is estimated that around 12.9 million units of EEE were collected at the specified collection points in 2008 (Ministry of Environment, Japan, 2010). In Canada, it is estimated that 5 million units of EEE are disposed of every year (Deathe et al., 2008) accumulates, while in Korea during 2004 over 3 million computers and 15 million mobile phones reached their end-of-life (Hyunmyung & Yong-Chul, 2006).

The same scenario applies to mobile phones and other handheld electronic items used in present society. Each year over 130 million mobile phones in the USA and over 105 million mobile phones in Europe reach their end-of-life and are thrown away (Canning, 2006). As a result used EEE, commonly known as e-waste and also known as waste electrical and electronic equipment (WEEE), has become a serious social problem and an environmental threat to many countries worldwide. The United

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Nations (UN) estimate that, collectively, the world generates 20–50 million tonnes of e-waste every year (Schwarzer et al., 2005). E-waste also contains a number of toxic substances, including plastics and heavy metals, such as lead, nickel, chromium, cadmium, arsenic and mercury.

A recent report released by the UN (UNEP and UNU, 2009) predicts that by 2020 e-waste from old computers in South Africa and China will have jumped by 200–400% and by 500% in India compared with 2007 levels. It also states that by 2020 e-waste from discarded mobile phones will be about 7 times higher than 2007 in China and 18 times higher in India. The report also cites that in the USA more than 150 million mobiles and pagers were sold in 2008, up from 90 million 5 years before; globally, more than 1 billion mobile phones were sold in 2007, up from 896 million in 2006. The UN report also estimates that countries like Senegal and Uganda can expect e-waste flows from personal computers alone to increase 4–8-fold by 2020.

There are growing concerns that most of the e-waste generated in developed countries is ending up in developing countries that are economically challenged and lack the infrastructure for environmentally-sound management (ESM) of e-waste resulting in adverse socio-economic, public health and environmental impacts of toxics in e-waste. This article aims to present a review of challenges and issues faced by Asian countries in managing their e-waste in a sustainable way.

Global generation of e-waste

The generation of reliable data on the exact amount of e-waste generated in different regions of the world is difficult to achieve as the amount of used WEEE reaching its end-of-life cannot be measured directly with some reliability. Most of the estimates available are based upon predictions made incorporating production or sales data, and the estimated life span of the WEEE. Several countries have conducted e-waste inventories to determine the quantities and composition of e-waste. Unlike other used products, there is a tendency for consumers to store used WEEE at home and in offices thus making estimation a challenging task. Ongondo et al. (2011) summarises some of the available e-waste data/estimates from different sources (Table 1).

Table 1. Global generation of e-waste.

Country	E-waste generation (tonnes/year)	Per capita generation (kg/person)
Germany	1,100,000 (2005)	13.3
UK	940,000 (2003)	15.8
Switzerland	66,042 (2003)	9
China	2,212,000 (2007)	1.7
India	439,000 (2007)	0.4
Japan	860,000 (2005)	6.7
Nigeria	12,500	
Canada	86,000 (2002)	2.7
South Africa	59,650 (2007)	1.2
Argentina	100,000	2.5
Brazil	679,000	3.5
USA	2,250,000 (2007)	7.5
Kenya	7350 (2007)	0.2

An estimation of global generation of e-waste by Robinson (2009) gives an annual production of 20-25 million tonnes.

E-waste categories

The proper definition and identification of categories of e-waste are critical for the sound management of e-waste. Townsend (2011) quotes the definition e-waste from the EU as:

> *'equipment which is dependent on electric currents or electromagnetic fields to work properly and equipment for the generation, transfer, and measurement of such current and fields designed for use with a voltage rating not exceeding 1000 Volts for alternating current and 1500 Volts for direct current.'*

On the above basis, e-waste includes common items, such as computers, televisions, mobile phones, iPods, printers, fluorescent lamps, power tools and toys etc., which basically covers most of the small and large appliances used in households and business in modern society. Table 2 summarises the main categories of e-waste as defined by the EU's Revised WEEE Directive (explained in the section *International policies, regulations, conventions and initiatives related to e-waste*).

Problems and opportunities associated with e-waste

Description of problems

Problems associated with e-waste are becoming well known in the scientific literature. In general, WEEE is a complicated assembly of a number of different materials, many of which are highly toxic. For example, the production of semiconductors, printed circuit boards, disc drives and monitors used in computer manufacturing utilises many hazardous chemicals. Computer central processing units (CPU) contain heavy metals, such as cadmium, lead and mercury. Printed circuit boards (PCB) contain heavy metals, such as antimony, silver, chromium, zinc, lead, tin and copper. In WEEE, lead is used mainly in cathode ray tubes (CRTs) in monitors, tin–lead solders, cabling, PCBs and fluorescent tubes (Herat, 2008c).

E-waste also contains brominated flame retardants (BFRs), such as polybrominated biphenyls (PBB) and polybrominated diphenylethers (PBDEs), which are used in PCBs, connectors, covers and cables. There is a growing body of literature suggesting that BFRs have negative environmental and health effects, and, hence, should be limited or replaced altogether (Barontini and Cozzani, 2006; Birnbaum and Staskal, 2004; Herat, 2008a). Exposure to PBDEs of personnel working in e-waste recycling facilities and of people in surrounding areas has been studied by researchers worldwide (Cai and Jiang, 2006; Han et al., 2009; Jakobsson et al., 2002; Julander et al., 2005; Leung et al., 2006, 2007; Liu et al., 2009; Pettersson-Julander et al., 2004; Sjodin

Table 2. Six categories of e-waste.

E-waste category	Some examples of products
Temperature exchange equipment	Refrigerators, freezers, air conditioning equipment, dehumidifying equipment, heat pumps, radiators containing oil and other temperature-exchange equipment
Screens, monitors and equipment containing screens that have a surface greater than 100 cm^2	Screens, televisions, liquid crystal display (LCD) photo frames, monitors, laptops, notebooks
Lamps	Straight fluorescent lamps, compact fluorescent lamps, fluorescent lamps, high density discharge lamps, low pressure sodium lamps, light emitting diode (LED)
Large equipment (any external dimension greater than 50 cm)	Washing machines, clothes dryers, dish washing machines, cookers, electric stoves, electric hot plates, musical equipment, large printing machines, copying equipment, large medical devices, etc.
Small equipment (no external dimension more than 50 cm)	Vacuum cleaners, carpet sweepers, microwaves, irons, toasters, electric knives, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, video recorders, hi-fi equipment, toys, smoke detectors, etc.
Small information technology and telecommunication equipment (no external dimension more than 50 cm)	Mobile phones, global positioning systems, pocket calculators, routers, personal computers, printers, telephones

et al., 2001; Tue et al., 2010a; Wang et al., 2009a)). PBDEs are also found in the environment around some e-waste recycling facilities. A study conducted by Sepúlveda et al. (2010) on the levels of PBDEs in air, bottom ash, dust, soil, waster and sediments in e-waste recycling sites in China and India found high concentrations on PBDEs exceeding, by several orders of magnitude, concentrations of other industrial or urban areas.

Description of opportunities

Although e-waste is usually regarded as a problem due to the environmental damage it has caused if not properly dealt with in an appropriate way, it is easy to overlook the opportunities associated with e-waste, especially at a time where resource use and depletion are also global issues. Figure 1 shows that metals account for nearly 60% of the e-waste stream and Table 3 shows the use of certain valuable metals in WEEE manufacture.

Table 3. Metals used for electric and electronic equipment (EEE) manufacture.

Metal	Annual production tonnes (2006)	Demand for EEE Tonnes/y	Demand/ production %
Silver	20,000	6000	30
Gold	2,500	300	12
Palladium	230	33	14
Platinum	210	13	6
Ruthenium	32	27	84
Copper	15,000,000	4,500,000	30
Tin	275,000	90,000	33
Antimony	130,000	65,000	50
Cobalt	58,000	11,000	19
Bismuth	5600	900	16
Selenium	1400	240	17
Indium	480	380	79

Source: UNEP and UNU (2007).
The table shows that although e-waste is seen as a problem, it is also important to find effective ways to recover the resources contained in it.

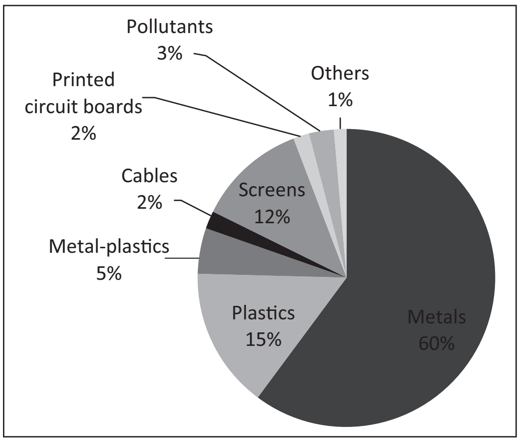

Figure 1. Metal fraction in electrical and electronic equipment (WEEE). Adapted from Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, et al. (2005) Global perspectives on e-waste. *Environmental Impact Assessment Review* 25: 436–458 with permission from Elsevier.

International policies, regulations, conventions and initiatives related to e-waste

E-waste regulations in the European Union

WEEE Directive. The aim of the WEEE Directive is to minimise the impact of electrical and electronic goods on the environment by increasing reuse and recycling, and reducing the amount of WEEE going to landfill. To achieve this, producers are made responsible for financing the collection, treatment and recovery of waste electrical equipment, and the distributors are obliged to allow consumers to return their waste equipment free of charge. The Directive was agreed by European Parliament on 13 February 2003, transposed into Member State legislation by 13 August 2004 and came into force on 13 August 2005 (European Union, 2003b).

In 2007, the United Nations University (UNU)-led consortium was contracted by the EU to analyse the environmental, economic and social impacts of implementing the WEEE

Directive in 27 EU member states (Khetriwal et al., 2011). The study found that after four years of operation of the WEEE Directive, only about a third of e-waste was treated in line with these laws, and that the other two thirds was going to landfill and, potentially, to sub-standard treatment sites outside the EU. As a result, the WEEE Directive was revised in late December 2011. The revised Directive requires, by 2016, that all member states collect 45% of the EEE put on the market, and increase this to 65% in 2019.

Restriction of Hazardous Substances Directive. The Restriction of Hazardous Substances (RoHS) Directive was created by the European Parliament in 2003 in recognition of the fact that not all hazardous substances in WEEE can be recycled or disposed of in an environmentally sound manner. Thus, a ban on the use of certain substances in electrical and electronic equipment was imposed. The RoHS directive came into effect on 1 July 2006 and applies to new electrical and electronic equipment put on the European market on or after 1 July 2006. It names six substances of immediate concern: lead, mercury, cadmium, hexavalent chromium, PBB and PBDE. The Directive has provisions for adaptation to scientific and technical progress, such as establishing, as necessary, maximum concentration values, exempting materials and components of electrical and electronic equipment, and carrying out a review of each exemption at least every four years (European Union, 2003a).

E-waste regulations in Japan

The Japanese government has formulated two laws to deal with the e-waste in Japan. The first law is called the Law for the Promotion of Effective Utilisation of Resources (LPUR) and the second law is called the Law for Recycling Specified Kinds of Home Appliances (LRHA). LPUR covers personal computers and small-sized batteries, while LHRA deals with televisions, refrigerators, washing machines, air conditioners and clothes dryers. While LPUR encourages the manufacturers to voluntarily help e-waste recycling to reduce the generation of waste, LRHA imposes more compulsory obligations on the consumers and manufacturers. When disposing of home appliances consumers are required to pay for the cost of transportation and recycling. Recycling fees range from 2400 yen (washing machines) to 4600 yen (refrigerators). Manufactures are responsible for establishing proper e-waste recycling facilities and are required to achieve compulsory recycling rates such as 70% for air conditioners, 60% for refrigerators and 65% for washing machines (Chung and Murakami-Suzuki, 2008).

An amendment to the LPUR took place on 1 July 2006 when the Japanese version of the RoHS (also known as J-Moss or JIS C 0950) was introduced. This amendment mandates that manufacturers provide material content declarations for certain categories of electronic products from sold after 1 July 2006. Manufacturers and importers are required to label their products and provide information on the six EU RoHS substances: lead, mercury, chromium VI, cadmium, PBB and PBDE. Apart from manufacturers, importers of the items listed above must meet the Design for Environment (DfE) criteria, which are required for domestic manufacturers. The Japan RoHS does not ban products containing restricted substances (Sugita, 2006).

E-waste regulations in China

China is considered to be one of the fastest growing economies around the world, and the largest exporter of information and communication technology products to the world—surpassing Japan, the EU and the USA. It is also estimated that total amount of e-waste generated in China is around 1.11 million tonnes per year, arising mainly from EEE manufacturing and production processes, end-of-life of household appliances and information technology products, and import from other countries (Xuefeng et al., 2006). China has become a key player in the global e-waste recycling system, employing over 0.7 million people in 2007, of whom 98% were employed in the informal recycling sector (Jinglei et al., 2009). Numerous estimates are presented in the literature regarding the amount of e-waste generated in China. For example, Yang et al., 2008 estimate that the total amount of e-waste generated in China in 2003 was 55.9 million Units and predicted it to increase to 105.3 million (3.3 million tonnes) by 2010. Li et al. (2006) forecasted that e-waste in China would reach 162 million Units (4 million tonnes) by 2010. However, Chung (2011) studied and compared numerous estimates published on e-waste quantities in China, and found large discrepancies in the predicted amounts and a lack of transparency of data collection and computational methods.

The environmental and health impacts of e-waste generated in China and also imported from other countries are becoming well known in the general media and scientific literature. One of the first studies to document the environmental and health impacts of improper management of e-waste in China was conducted by the Silicon Valley Toxics Coalition (SVTC) and the Basel Action Network (BAN), and published in 2002 through a now well-known document 'Exporting Harm: The High-Tech Trashing of Asia'. This report asserts that 50–80% of e-waste collected for recycling in the USA is exported to developing nations (Puckett et al., 2002).

In order to address the problem of e-waste, the Chinese government has taken a number of measures, including prohibiting the import of e-waste and other hazardous waste since 2000, and implementing the Technical Policy on Pollution Prevention and Control of Waste Electrical and Electronic Products (2006) and the Administrative Measures for the Prevention and Control of Environmental Pollution by Electronic Waste (2007), which has been in force since 2006. Also, China has recently introduced a licensing scheme for proper e-waste recycling, which prohibits informal recycling by unauthorised recycling firms (Li et al., 2011a).

China's problem with e-waste has come about mainly because of recycling operations conducted by labour-intensive small and informal business sectors which lack the capacity to handle such wastes in a proper manner. In order to legalise the management of waste electrical and electronic products, and promote the comprehensive utilization of resources and development of the circular economy, as well as protecting the environment, on 5 March 2009 the State Council adopted and promulgated the *Administration Regulation for the Collection and Treatment of Waste Electrical and Electronic Products*, namely Chinese WEEE. The regulations came into effect on 1 January 2011. The new regulation consists of 5 Chapters and 35 Articles. Article 4 allows for a 'Catalog for Disposal of Waste Electrical and Electronic Products' (the main deviation from EU's WEEE Directive). The first list of controlled products was announced in December 2010 and took effect on 1 January 2011. The first list includes televisions, refrigerators and freezers, washing machines, air conditioners and personal computers. Article 6 stipulates a system of licensing for recovery processing of waste electrical and electronic products. The environmental protection department of the municipal People's Government, with a district division, is authorised to examine and approve qualification of enterprises in the line of recovery processing of electrical and electronic products. The complete analysis of the new regulations and other regulatory measures on e-waste in China can be found in Chung and Zhang (2011).

E-waste regulations in India

In India, e-waste is a major issue owing to the generation of domestic e-waste, as well as imports from developed countries. India's electronic industry is one of the fastest growing industries in the world. It is estimated that per capita ownership of personal computers grew by 604% during the period 1993–2000 compared with the world average of a 181% increase during the same period (Sinha-Khetriwal et al., 2005). A study conducted by Dwivedy and Mittal (2010) on future trends in computer waste generation in India estimated that around 41–152 million computers will become obsolete in India in 2020. It also estimated that total annual e-waste generation in India is between 1,46,000 and 3,30,000 tonnes, and is expected to reach 4,70,000 tonnes by 2011. Another estimate states that in 2007 India generated 380,000 tonnes of e-waste from computers, televisions and mobile phones only, and that figure is set to reach 800,000 tonnes by 2012 (Rathore et al., 2011). The same study also estimates that India has 15 million new mobile phone users every month, and the total mobile subscriber base is expected increase from current 652 million to 1.159 billion by 2013.

In 2005, India's Central Pollution Control Board developed guidelines for ESM of e-waste in India. E-waste in India is not regulated at the present time. However, the Ministry of Environment and Forest as part of the Environmental Protection Act of India has enacted the 'E-waste (Management and Handling) Rule of 2011' which took effect on 1 May 2012. The rule mandates producers to be responsible for the collection and financing the systems according to extended producer responsibility concept. The rule clearly defines the responsibilities of the producer, collection centres, consumer or bulk consumers, dismantlers and recyclers.

E-waste regulations in the USA

It is widely known that the USA is one of the largest producers of e-waste in the world. According to one estimate for the year 2000, the USA generated 2.2 million tonnes of e-waste, which included 859,000 tonnes of video products, 348,000 tonnes of audio products and 917,000 tonnes of information technology products (Gibson and Tierney, 2006). The US Government Accountability Office (GAO) reports that over 100 million computers, monitors and televisions become obsolete in the USA each year, and that number is growing. It also refers to a National Safety Council forecast that in 2003 about 70 million computers became obsolete, of which only 7 million were recycled, and an International Association of Electronics Recyclers (IAER) report that estimated about 20 million televisions become obsolete each year—a number that is expected to grow significantly as CRT technology is replaced by plasma technology. The GAO report also refers to US Environmental Protection Agency (US EPA) data which indicate that less than 4 million computer monitors and 8 million televisions are disposed of in landfills each year, and only 19 million computers were recycled in 2005 (United States Government Accountability Office, 2005).

In the absence of federal legislation, individual states have begun to address the issue by developing and adopting their own e-waste legislation covering areas such as e-waste landfill disposal bans and comprehensive recycling legislation. Currently, 24 of the 50 states have enacted their own regulations. Thirteen states (California, Connecticut, Hawaii, Illinios, Indiana, Maine, Minnesota, New Jersey, New York, North Carolina, Oregon, Rhode Island and South Carolina) have banned the landfill disposal of various types of electronic waste. While California has adopted an advanced recycling fee system the other states have, in general, settled for an extended producer responsibility system where costs are borne by the manufacturer or retailer (Townsend, 2011) .

During the summer of 2011 the United States Presidential Administration released the 'National Strategy for Electronics Stewardship', which is the driving force for improving the design of electronics products and enhancing the management of used electronics in the USA. This long-awaited strategy describes a number of activities that the federal government will implement in the coming years to ensure the proper handling of used electronics and also to encourage the growth of the US electronics recycling industry (US EPA, 2011).

E-waste regulations in Australia

The Australian government reported recently that in 2007/8, 31.7 million new televisions, computers and computer products were sold in Australia. During this period 16.8 million units of this equipment also reached their end-of-life, with 88% sent to landfill and only 9% recycled. The government also estimates that the number of televisions, computers and computer products reaching their end-of-life is expected to grow to 44 million by 2027/28. The Australian state and federal governments are currently working together to impose regulations directed toward extended producer responsibilityon computer manufacturers and retailers with a view to managing this huge and growing waste stream (EPHC, 2010).

To fulfill the key commitments under the National Waste Policy, the Australian government passed the 'Product Stewardship Act 2011' on 8 August 2011. The Act seeks to address the environmental, health and safety impacts of products. The implementation of the Act will help reduce hazardous substances in products and in waste, avoid and reduce waste, and increase recycling and resource recovery. The Act provides a framework for mandatory, co-regulatory and voluntary product stewardship. Under the Product Stewardship Act, the *Product Stewardship (Televisions and Computers) Regulations 2011,* also referred to as the 'National Television and Computer Recycling Scheme' came into effect on 8 November 2011 to support a co-regulatory recycling scheme for televisions, computers, printers and computer products. The Scheme recycling target is set at 30% of waste arising in 2012–2013 increasing to 80% of waste arising in 2021–2022. The scheme also includes a material recovery target of 90%, which will come into effect during 2014–2015. The scheme is expected to be implemented in 2012.

The complete details of the scheme can be accessed via http://www.environment.gov.au/settlements/waste/ewaste/index.html.

Basel Convention

Officially known as the 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal', the Basel Convention is the most comprehensive global environmental agreement on hazardous wastes ever developed (www.basel.int). Its main aim is to protect human health and the environment from adverse impacts resulting from the generation, management, transboundary movements and disposal of hazardous and toxic wastes. It came into force on 5 May 1992 in accordance with article 25(1) of the Convention. As of September 2010 there are 178 parties signed up to the Convention.

The Basel Convention's Conference of the Parties (COP) has made several decisions to achieve ESM of electrical and electronic waste. At its sixth meeting (COP6) in December 2002, electronic wastes were identified as a priority waste stream in the strategic plan for the implementation of the Basel Convention up to 2010. In 2006, the Basel Convention's eighth meeting of the COP (COP8) was held in Nairobi with the theme 'Creating innovative solutions through Basel Convention for the environmentally sound management of electronic wastes'. During this meeting ministers, executive officers, civil-society representatives and other relevant participants from around the world participated in a high level world forum on e-wastes. As a result, the 'Nairobi declaration on the Environmentally Sound Management of Electrical and Electronic Waste' was adopted by COP8 as decision VIII/2. The details of this declaration are found in Annexes I and II of UNEP (2007a) and Annex IV of UNEP (2007b). The Basel Convention has conducted number of workshops on ESM of e-waste in the Asia-Pacific region, the latest one being in Vietnam in 2009.

One of the obstacles for adopting the Basel Convention for used EEE is the use of common Harmonised System (HS) Code for both new and old EEE. This is being currently addressed by the World Customs Organisation (WCO). Japan has already developed different HS Codes for a number of used EEEs and has been applied since January 2008 (Yoshida et al., 2008).

The Basel Convention has developed two important initiatives to encourage private sector participation in ESM of e-waste. Launched in 2002, the 'Mobile Phone Partnership Initiative' (MPPI) has overall objectives for better product stewardship, changing consumer behaviour, promoting best reuse, refurbishing, material recovery, recycling and disposal options, and mobilising political and institutional support for ESM. A guidance document on the ESM of used and end-of-life mobile phones was adopted by the eighth Conference of the Parties (http://archive.basel.int/industry/mppi.html). The Partnership for Action on Computing Equipment (PACE) was adopted by the Basel Convention in June 2008. The main objective of the PACE is to provide new and innovative approaches for addressing emerging issues on used and end-of-life computing equipment (http://archive.basel.int/industry/compartnership/index.html).

In July 2011, the Basel Convention released the 'Technical guidelines on transboundary movements of e-waste, in particular regarding the distinction between waste and non-waste'. This is still in draft form (http://basel.int/cop10/data/COP10-INF/documents/i05e.pdf).

Other international treaties and initiatives related to e-waste

The Basel Convention Partnership on the Environmentally Sound Management of E-waste in Asia Pacific Region was launched in 2005 by the secretariat of the Basel Convention with funding from the government of Japan. Its goal is to enhance the capacity of parties to manage e-waste in an environmentally sound manner through the building up of public–private partnerships and by preventing illegal traffic.

To address the issue of transboundary movement of e-waste, the government of Japan proposed the development of the 'Asian Network for Prevention of Illegal Transboundary Movement of Hazardous Wastes' in 2003. The network aims at facilitating the exchange and dissemination of information on transboundary movements of hazardous wastes and selected used products among the Northeast and Southeast Asian countries, and assists in formulating appropriate legislative responses (http://www.env.go.jp/en/recycle/asian_net/).

The 'Solving the E-Waste Problem (StEP)' initiative, officially launched on 7 March 2007, aims to standardise the global e-waste recycling processes to harvest valuable components of WEEE, extend the life of products and markets for their reuse, and to harmonise world legislative and policy approaches to e-waste management (http://www.step-initiative.org). The initiative is a new global public–private partnership with the participation of major high technology manufacturers, governmental organisations, academic and research institutions, and non-governmental organisations (United Nations University, 2007b).

The G8 3Rs Initiative (Reduce, Reuse and Recycle) was introduced by Japan during the G8 (group of eight major industrial nations consisting of Japan, Russia, UK, France, Italy, Germany, USA and Canada) Summit in June 2004. During the Asia 3Rs Conference held in Tokyo during November 2006 where 20 Asian countries, 6 G8 countries and 8 international organisations participated, progress and issues related to ESM of e-waste in the Asian region were discussed, and delegates from Asian countries and experts made presentations on case studies of e-waste management. The Regional 3R Forum in Asia proposed by the government of Japan and managed by the United Nations Centre for Regional Development (UNCRD) was officially inaugurated in November 2009 and the International Partnership for Expanding Waste Management Services in Local Authorities (IPLA), launched in 2011, promotes sustainable management of e-waste and can be accessed via the UNCRD website (http://www.uncrd.or.jp/).

Upstream reduction of e-waste

Currently, a major problem that exists in the manufacturing process of computer equipment is that of its design. The manufacturing process in the electronics industry is linear in nature and adheres to the standard 'profit'-focused approach. A computer manufacturer or other industry player may well have an environmentally-certified manufacturing plant and be extremely mindful of its eco-responsibility. However, if the end product is not 'clean' in process, then the impact of any improvement through accreditation is weakened. Design-for-the-environment (DfE) or eco-design, also, at times, refer to cleaner production, as a result of major regulatory changes that have, and are, taking place internationally. Together with pressure from end-users, DfE is becoming an increasingly important priority for manufacturers of electronic equipment. A good example of upstream reduction through DfE is lead-free soldering in electronics manufacture (Herat, 2008b).

In order to assist in improving environmental performance within the electronics industry, there has been a growing perception of the need to introduce measures that will improve the ability of governments and corporations to improve environmental performance. This includes a variety of initiatives and legislation that have been introduced internationally. These include global guidance standards as published by the International Standards Organisation (ISO), and work by the Organisation for Economic Cooperation and Development (OECD) and the United Nations Environment Programme which provide information on product stewardship and extended producer responsibility (EPR), and guidance on public procurement with a view to improving environmental performance. Table 4 shows some possible approaches to EPR with some examples.

Specific challenges, issues and opportunities related to e-waste management in Asian countries

Environmental and health impacts of e-waste management in Asian countries

In contrast to the formal e-waste recycling practices in industrialised countries, a number of Asian countries are adopting rudimentary recycling practices to deal with the high amounts of e-waste imported from industrialised countries, as well as from domestic production. Open burning of e-waste is widely used to recover metals, such as steel, aluminium and copper from wires, capacitors and other components of e-waste. The informal recycling sector is very active in a number of Asian countries where harmful techniques in de-soldering circuit boards to recover valuable metals are very common. Open dumping of non-valuable fractions is also common, and has caused significant environmental and health impacts. Figure 2 illustrates the health risk implications of improper disposal of e-waste.

Among the Asian countries, the environmental and health impacts of e-waste management in India and China are well documented in the scientific literature. Brigden et al. (2005) conducted a comprehensive study regarding environmental contamination at a number of e-waste recycling sites in China and India found very high levels of lead, polybrominated diphenyl ethers (PBDEs), polychlorinated dibenzodioxins and furans (PCDD/Fs) and polybrominated dibenzodioxins nd furans (PBDD/Fs) in air, dust, sediments and freshwater causing significant environmental damage. A similar study conducted by Brigden et al. (2008) in Ghana found high levels of lead and chemicals, such as phthalates bis(2-ethylhexyl)phthalate (DEHP) and dibutyl phthalate (DBP) in samples taken from e-waste recycling sites. Two review articles published by Sepúlveda et al. (2010) and Zheng et al., (2008) studied the environmental fate and effects of hazardous substances released from e-waste recycling in China and India, and polychlorinated dibenzo-p-dioxins and dibenzofurans in China around e-waste recycling facilities, respectively, and found very similar results, confirming the previous studies. Tables 5–7 report on research undertaken to assess

Table 4. Some approaches to EPR and related examples.

Type of EPR	Example
Product take-back	Mandatory, voluntary or negotiated take-back programs
Regulatory approaches	Prohibition of hazardous materials, co-regulations
Economic instruments	Advanced recycling fees, deposit–refund schemes, fees on disposal

Source: Widmer et al., (2005).

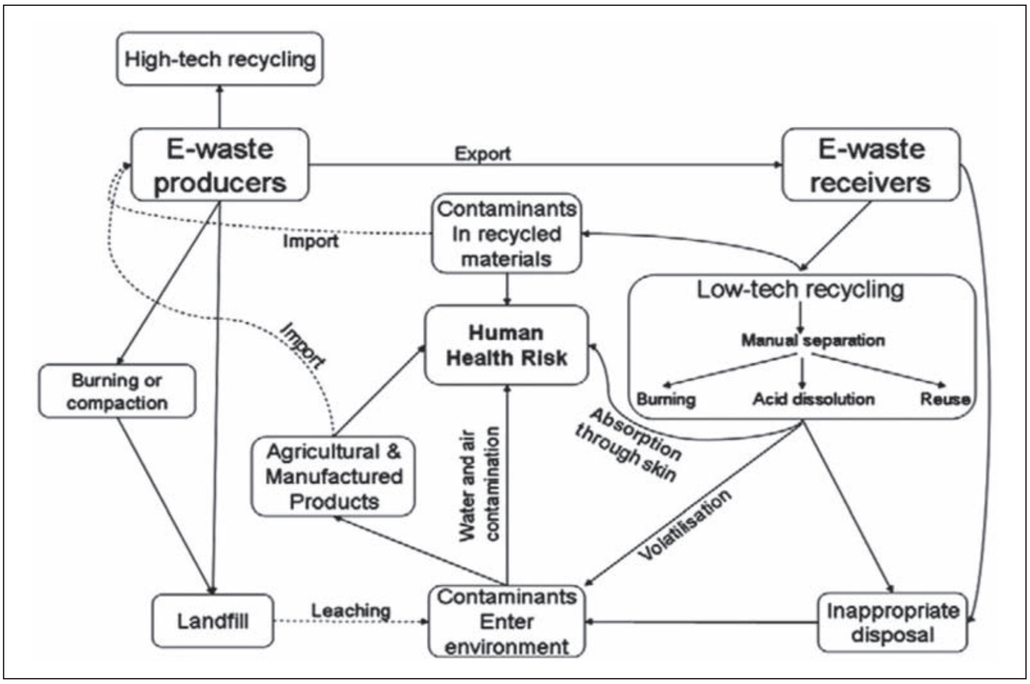

Figure 2. Health-risk implications of WEEE e-waste.

Table 5. Studies on impacts on sediments near e-waste recycling sites.

Contaminants in sediments and study area	Reference
PCBs, PAHs and heavy metals of surface sediments of Nanguan River, Taizhou, East China	Chen et al. (2010)
Contamination in agricultural soil from range of metals, PAHs and PCBs in Taizhou, East China	Tang et al. (2010a)
Contamination of sediments by heavy metals, PAHs and PCBs in the town of Wenling, e-waste recycling city, Taizhou, China	Tang et al. (2010b)
Heavy metal contamination in soils and vegetables near an e-waste processing site, Longtang, Guangdong province, China	Luo et al. (2011)
Heavy metal contamination of surface soil in an electronic waste dismantling area in Guiyu, Guangdong province, China	Li et al. (2011a)
Contamination by trace elements at e-waste recycling sites in Bangalore, India	Ha et al. (2009)
Concentrations and profiles of PCDD/Fs in discarded electronic waste open burning site in China	Mingzhong et al. (2010)
Levels and isomer profiles of dechlorane plus (DP) in the surface soils from e-waste recycling areas and industrial areas in South China	Yu et al. (2010)
PBDEs in soils and vegetation near an e-waste recycling site in South China	Wang et al. (2005 2011b))
Major pollutants in soils of abandoned agricultural land contaminated by e-waste activities in Hong Kong	Lopez et al. (2011)
PBDE concentrations near e-waste recycling site in China	Cai and Jiang (2006), Leung et al. (2006, 2007)
Trace metal contamination of sediments in an e-waste processing village in China	Wong et al. (2007)

PCB, polychlorinated biphenyls; PAH, polycyclic aromatic hydrocarbons; PCDD/F, Polychlorinated dibenzodioxins and furans; PBDE, polybrominated diphenylethers.

the impacts of e-waste recycling in developing countries on the sediments, humans and biota respectively.

Table 5 summarises the studies undertaken near Nanguan River, which runs through an e-waste recycling area of Taizhou in East China, to investigate the impacts of heavy metals, PCBs, polycyclic aromatic hydrocarbons (PAHs), PCDD/Fs and PBDEs on sediments near e-waste recycling sites. The study by Chen et al., (2010) investigated the level of PCBs from samples taken from four household workshops and two industrial parks. PCBs were detected ranging from 16–2990 ng/g dw, exceeding the Canadian freshwater sediment quality guideline of 34 ng/g dw by 20–90 times. Further investigation into the impact of PCBs near an e-waste recycling workshop in an unnamed town in China revealed mean PCB concentrations of 142.3 µg/kg, significantly exceeding the PCB levels in Dalian, a rural town in China (1.34 µg/kg), Hong Kong (2.45 µg/kg) and the global mean (5.4 µg/kg)

Table 6. Studies on impacts on humans near e-waste recycling sites.

Impacts on humans and study area	Reference
Heavy metals in hair from occupationally and non-occupationally-exposed populations in an e-waste recycling area in Longtang, South China	Zheng et al. (2011)
Heave metals in placentas from China's Guiyu area	Guo et al. (2010)
Urinary levels of heavy metals in people living around e-waste sites in Taizhou, Zhejiang province, Southeast China	Wang et al. (2011a)
Changes of urinary 8-hydroxydeoxyguanosine levels and burden of heavy metals around an e-waste dismantling site located in Taizhou	Wang et al. (2010)
Assessment of cadmium exposure for neonates in Guiyu e-waste pollution site	Li et al. (2011b)
Human exposure to PCBs, and BFRs such as PBDEs and HBCDs in Ghana	Asante et al. (2011)
Exposure of Chinese residents to PBBs, PBDEs and PCBs in an e-waste recycling site in Zhejiang province	Zhao et al. (2008)
Correlations of PCBs, dioxin and PBDEs with thyroid stimulating hormorne (TSH) in children	Han et al. (2011)
Distribution of PCDD/Fs, PCBs, PBDEs and organochlorine residues in children's blood from Zhejiang region in China	Shen et al. (2010)
Accumulation of PCBs and BFRs in breast milk from women living in Vietnamese e-waste recycling sites	Tue et al. (2010a)
PBDEs in umbilical cord blood and relevant factors in neonates from Guiyu area	Wu et al. (2009)
Elevated body burdens of PBDEs, dioxins and PCBs on thyroid hormone homeostasis at an e-waste recycling site in China	Zhang et al. (2010a)
Elevated concentrations of PCDD/Fs and PBDEs in hair from workers at an e-waste recycling plant in Eastern China	Ma et al. (2011)
Human exposure to heavy metals in an electronic waste recycling area	Wang et al. (2009b)

PCB, polychlorinated biphenyls; BFR, brominated flame retardants; PBDE, polybrominated diphenylethers; HBCD, hexabromocyclododecane; PBBs, polybrominated biphenyls; PCDD/F, polychlorinated dibenzodioxins and furans.

Table 7. Studies on impacts on biota near e-waste recycling sites.

Impacts on biota and study area	Reference
Exposure to PCBs through inhalation, dermal contact and dust ingestion at Taizhou area, China	Xing et al. (2011)
Particle bound PCDD/Fs in the atmosphere of an e-waste dismantling area in China	Wen et al. (2011)
PBDEs and PCDD/Fs in surface dust at an e-waste processing site in Southeast China	Leung et al. (2011)
Dechlorane plus (DP) in air and plants at an e-waste site in China	Chen et al. (2011)
Bioaccumulation of organohalogen pollutants in the aquatic biota from an e-waste recycling region in South China	Zhang et al. (2010b)
PBDEs in chicken tissues and eggs from an e-waste recycling area in Southeast China	Qin et al. (2011)
Bioaccumulation, maternal transfer and elimination of PBDEs in wild frogs	Liu et al. (2011)
Level of PBDE in fish samples in Guiyu area, China	Luo et al., 2007a, 2007b)
PBDE levels in mangrove wetland in India	Binelli et al. (2007)
Atmosphere levels and cytotoxicity of PAHs and heavy metals	Deng et al. (2006)
Dioxin levels in house dust from Vietnamese e-waste recycling sites	Tue et al. (2010b)

PCB, polychlorinated biphenyls; PCDD/F, polychlorinated dibenzodioxins and furans; PBDE, polybrominated diphenylethers; PAH, polycyclic aromatic hydrocarbons.

(Tang et al., 2010a). Similar findings were noted for PAHs, where levels ranged over from 2820 to 7880 ng/g dw, which is 8–22 times higher than other towns in China (Chen et al., 2010). An investigation into heavy metals at an abandoned informal recycling site in China revealed significantly high metal concentrations compared with China's environmental quality standard for soils: lead (13 times), cadmium (50 times), zinc (35 times) and copper (363 times) (Li et al., 2011b). Similar findings were found in an e-waste processing site in South China, where levels of Cu ranged from 1500–21,400 mg/kg dw (Chinese standard for soil: 50 mg/kg dw), Zn 682–8970 mg/kg dw (standard: 47 mg/kg dw) (Luo et al., 2011).

A number of studies have been undertaken to investigate the impacts of heavy metals on humans living near e-waste recycling sites, as summarised in Table 6. Concentrations of lead, cadmium, chromium and nickel in human placentas in women living near Guiyu in China revealed that 41.6% women have palladium levels exceeding 500 ng/g wt compared with 24.4% women at the control site (Guo et al., 2010). A similar result was found for cadmium near an e-waste recycling site in China where urinary cadmium levels were found to be significantly high (0.72 μg/l) compared with the control site (0.27 μg/l) (Wang et al., 2011a). A number of studies have also confirmed high levels of PCBs and PBDEs in humans living near e-waste recycling sites. An investigation into concentrations of PCBs and PBDEs in the blood of children living near an e-waste recycling plant in China revealed high concentrations of PCBs (484 ng/g compared with 255 ng/g in the control area) and PBDEs (664 ng/g compared with 376 ng/g in the control area) (Han et al., 2011). A similar study done in the same area found PCB levels of 40 ng/g (WHO standard: 11.9 pg/g) and PBDE levels of 32 ng/g (WHO standard: 10.3 pg/g) (Shen et al., 2010). Another study investigating the levels of PBDEs and PCDD/F in human hair from workers at an e-waste recycling plant in Eastern China revealed concentrations of PBDEs ranging from 22.8–1020 ng/g dw (three times higher than control site) and PCDD/F ranging from 126–5820 pg/g dw (18 times higher than control site) (Ma et al., 2011).

Issues and challenges for ESM of e-waste

The issue of ESM of e-waste is a global problem arising from transboundary movement among all countries and regions, and thus requires global solutions. As noted elsewhere in this article large amounts of e-waste are currently being exported to developing countries for the purpose of reuse, refurbishment, recycling and recovery of precious materials. Today India, China, Philippines, Hong Kong, Indonesia, Sri Lanka, Pakistan, Bangladesh, Malaysia, Vietnam and Nigeria are among the favourite destinations for e-waste. However, recycling and recovery facilities in these countries operate in an environmentally unsound manner causing significant environmental and health impacts. The operations in these countries are well documented. Significant amounts of e-waste containing hazardous materials can be seen dumped in open-land and waterways. The major environmental and health impacts occur during open burning of e-waste to recover precious metals. In spite of these significant environmental and health impacts, recycling and recovery operations have generated a huge informal employment sector in these countries. In addition to receiving e-waste from developed countries, developing countries are also emerging as significant generators of e-waste themselves.

Another major issue faced by developing countries in dealing with e-waste is how to tackle the emerging informal e-waste recycling sector. In most developing countries formal recycling of e-waste using best practice technologies in modern recycling facilities is rare. As a result, most of the e-waste is managed using various improper methods, such as open dumps, backyard recycling and disposal into surface water bodies. It is common to see open burning of plastics to reduce e-waste volumes, copper wires to salvage valuable metals and acid leaching to recover precious metals from PCBs.

Part of the problem faced by developing countries is a lack of funds and investment to finance formal recycling infrastructures, and the absence of appropriate legislation to deal with the issue. EPR is seen globally as one of the most effective ways of dealing with the e-waste issue. However, unlike in the developed world, implementing EPR in developing countries is a major challenge for policy makers. For example, in their study into the application of EPR policies in e-waste recycling in China and Thailand Kojima et al. (2009) found two major difficulties in implementing EPR in developing countries. The first difficulty is in the government collecting funds from producers or imports if the goods are smuggled into the country, or if the small, sop-assembled products have a large share of the market. The second difficulty is in systems that create incentives for collectors and recyclers to over-report the amount of e-waste collected to gain extra subsidies from the fund. One of the other issues in implementing EPR in developing countries is the competition between the formal and informal recycling sectors to gain access to e-waste.

In many developing countries there is a trend where used WEEE flows from the cities to the countryside because of the lack ownership of WEEE in those regions (Nnorom & Osibanjo, 2008). In many such cases reuse is the norm, even with appliances that are beyond repair. Such scenarios make collection of e-waste difficult. Furthermore, recycling is undertaken by informal recyclers; hence, the task is assigned to producers and importers, and the collection of used WEEE becomes very difficult. It is also difficult to assign responsibility for products that have been repaired or modified, and smuggled into the country. The question is whether responsibility lies with the producer or the importer. Osibanjo and Nnorom (2007) have summarised following as the key challenges facing developing countries in the sustainable management of e-waste:

- the increasing volume of e-waste imported illegally into developing countries in the name of second-hand EEE—most of these are rarely tested for proper functionality, with 25–75% of it unusable e-waste junk;
- educating the public and government sector on the toxicity or hazardous nature of e-waste—this is also applicable to people involved in informal recycling;
- proper infrastructure for recycling of e-waste;
- locating funds and investment to finance proper e-waste recycling facilities;
- developing appropriate policies and legislation specifically to deal with e-waste;
- implementing mandatory or effective voluntary take-back schemes, such EPR.

Policy approaches in managing e-waste in Asian countries

As seen from our earlier discussions, there are numerous challenges to overcome before developing countries achieve ESM of e-waste. A number of workshops and studies have been conducted by organisations, such as the Basel Convention, to investigate the obstacles in developing countries to adoption of ESM of e-waste. These have identified lack of e-waste inventories; lack of trained personnel to enforce ESM practices; lack of legislation (including export and import rules); inadequate infrastructure to collect, handle, recycle and recover materials from e-waste; and lack of awareness about the health and environmental impacts of unsound e-waste management practices as the main obstacles in achieving ESM of e-waste.

Informal sector. To manage the emerging threat from e-waste, and owing to the urgency of the issue, a number of developing countries are looking into adopting policies and technologies that have already been implemented in developed countries where proper infrastructure is in place to manage e-waste. However, the economic, environmental and social situation in a number of these developing countries (located mainly in Asia and Africa) are different to the developed world hence the need for adaption, implementation and scaling-up of appropriate technologies that are more suited to local conditions. One of the key areas that developing countries need to concentrate on relates to how to deal with the informal e-waste recycling sector. It is important to note here that in many developing countries the informal sector is very active in activities related to the e-waste recycling chain. These informal recyclers are motivated by the precious materials contained in the e-waste stream and its market value. In countries such as India and China, where significant amount of e-waste recycling is taking place, informal collectors achieve very high collection efficiencies. In fact, informal collection of e-waste does not have any major adverse impacts on the environment. Instead, it leads to high collection rates and many economical and social benefits to poor areas of the community. The informal sector is also involved in the second stage of the e-waste recycling chain—dismantling pre-processing. Even here there are no major impacts on the environment; instead, there more economic and social benefits to the poorest communities. The last stage of the e-waste recycling chain where processes/techniques are necessary to extract valuable components, such as metals, is where the current environmental impacts are. Most informal recyclers utilise low-efficiency processes which result in major health and environmental impacts. For example, primitive technologies utilised by informal recyclers to extract raw materials from printed wire boards, wires and other metal-bearing components have very low material recovery rates and also result in major environmental impacts. The challenge for policy-makers in developing countries is how to achieve efficiencies in the informal sector at the same time as taking into account the environmental and social aspects of their operations.

Prohibiting and imposing fines on informal recycling have not helped in countries like China and India. This is because of the fact that informal recycling is undertaken by poor people and, as such, the government is unable to impose heavy fines, as the people cannot pay them. These governments then tried to regulate the informal e-waste recycling sector by licensing them. However, the effectiveness of such a scheme depends a lot on the responsibility of the disposer of e-waste. The challenge is how to deal with the e-waste disposer, who receives more money from unlicensed informal recyclers than from the licensed recyclers. Shinkuma and Managi (2010) argue that, generally, the disposers of e-waste are relatively richer than the recyclers hence the government can afford to place a heavy fine on them. However, the issue is with governments of developing countries that are unable to impose fines on e-waste disposers of developed countries, where most of the e-waste comes from. One solution is for governments in developing countries to cooperate with the governments of importing countries to impose fines on non-compliant exporters. Chi et al. (2011) argue that the emergence and growth of the informal sector in developing countries is the result of intricate interactions between economic incentives, regulation gaps, industrial interdependence and social reality, and predicted that the informal sector may remain an influential recycling force for years to come. They suggested the whole informal recycling chain must be thoroughly investigated with regard to which steps are environmentally harmless and should remain and which steps of the material mass flow should be changed for better downstream environmental and recycling performance.

Technology transfer. According to UNEP and UNU (2009), a decision on technology transfer cannot be made purely on technology only. For example, advanced high-technology, capital-intensive e-waste recycling processes adopted in highly industrialised countries may not be suitable for certain developing countries. Instead, low-technology, labour-intensive e-waste recycling processes may satisfy all the above objectives and, hence, there will be more potential for success. A sustainable e-waste recycling system in any country will always require a properly established policy framework and a financing scheme. It is important to consider the whole recycling chain and the logistics systems to build an effective financing scheme. UNEP and UNU (2009) cite a major pilot-scale e-waste recycling project in China and show how a fully-financed, state-of-the-art e-waste recycling plant can fail when not supported by a proper collection network and by the competition from the informal sector. The study found that the transfer of technology to e-waste recycling plants without taking into account the amount of e-waste available to be processed in such plants, social and cultural boundary conditions and the role of existing informal sector can result in the failure of such projects.

Financing. Financing e-waste collection schemes and allocating responsibilities along the downstream chain has always been a challenge for many countries around the world. EPR is seen globally as one of the most effective ways of dealing with the e-waste issues. However, unlike in the developed world, implementing EPR in developing countries is a major challenge to policy-makers. For example in their study into applying EPR policies to e-waste recycling in China and Thailand Kojima et al., (2009) found two major difficulties in implementing EPR in developing countries. The first difficulty was in the government collecting funds from producers, or imports if the goods are smuggled into the country or if small, shop-assembled products have a large share of the market. The second difficulty was in systems that created incentives for collectors and recyclers to over-report the amount of e-waste collected to gain extra subsidies from the fund. One of the other issues in implementing EPR in developing countries is competition between the formal and informal recycling sectors in gaining access to e-waste. Agamuthu and Victor (2011) have suggested that developing countries should sort out the basic waste-management issues of proper collection and disposal, including the required infrastructure for waste management, before tackling advanced issues, such as EPR.

In order for developing countries to move forward with EPR regulations, Akenji et al. (2011) have proposed that developing countries should move towards EPR in phases. They have identified competition with the informal waste management sector, poor infrastructure for waste collection and treatment, perception of e-waste, and poor international governance of import and export of e-waste as key challenges facing governments.

Case studies on issues or best practice of e-waste management

Bangladesh. Bangladesh adopted its National Environmental Policy in 1992, the Environmental Conservation Act in 1995 and Medical Waste Management Rules in 2008. Currently, there are no regulations specifically dealing with e-waste. However, the government of Bangladesh has given top priority to the preparation of 'Electrical and Electronic Waste (Management and Handling) Rules' in 2011. In addition, the government has already prepared a National 3R (Reduce, Reuse and Recycle) Strategy incorporating some aspects of e-waste management. Furthermore, two Rules—the Hazardous Waste Management Rule (under preparation) and the draft Solid Waste Management Rule (prepared and in the consultation stage)—could also accommodate issues related to e-waste (Ahmed, 2011).

Currently, there is no inventory of e-waste in Bangladesh. The Environment and Social Development Organisation (2010) estimates that Bangladesh produces about 2.8 million tonnes of e-waste every year, out of which 2.5 million tonnes is generated by e-waste from ship-breaking yards. The report also noted that the total number of computers, televisions and refrigerators purchased in 2006 was 600,000, 1.2 million and 2.2 million respectively. At the end of 2008 Bangladesh had 10.3 million televisions in use, with around 6 million televisions being scrapped every year as e-waste. As of May 2010 Bangladesh had 58 million mobile phone subscribers. It is estimated that around 25 million mobile phones will be discarded annually in Bangladesh. As for end-of-life management of electrical and electronic equipment, reuse is a common practice in Bangladesh. Dismantling and recycling is also a growing business undertaken mainly by the informal sector. Most of the e-waste in Bangladesh is dumped in open landfills, on farming land and in open water bodies, causing severe health and environmental impacts. The Environment and Social Development Organisation (2010) states that over 50,000 children are involved in the informal e-waste collection and recycling processes—40% of them in the ship-breaking yards. Every year around 15% of child workers die as a result of e-waste recycling and over 83% are exposed to toxic materials in e-waste, become sick and are forced to live with long-term illness.

Pakistan. Pakistan currently has no inventory or exact data on e-waste generation. Abbas (2011) estimates that Pakistan has currently around 100 million mobile phone subscribers. Pakistan has no regulations specifically targeting e-waste, although the National Environment Policy has been active since 2005. The Ministry of Environment overseas environmental protection, and the movement of chemicals and waste. There is no formal mechanism to manage e-waste at the national level. Therefore, people use different methods to manage e-waste locally. The informal recycling sector is very active and a number of workers, including children, earn their living by dismantling electronic scrap and extracting valuable metals. Open-burning and open-dumping of e-waste is very common in Pakistan.

Thailand. Thailand generated about 81,280 tonnes/year of e-waste in 2009, out of which electrical and electronic manufacturers generated about 20,000 tons/year. It was also estimated that e-waste generated from used televisions, computers, mobile phones, refrigerators, air conditioners and washing machines exceeded 2.5 million units in 2009. In Thailand it is also estimated that there are about 2000 electrical and electronic manufacturers, making it one of the largest manufacturers in the region. In addition, Thailand also had 9000 junk shops and 30 formal e-waste recycling facilities as of September 2010 (Komonweeraket, 2011). Thailand also suffers from issues such as lack of general awareness about e-waste, incomplete databases and inventories related to e-waste, lack of ESM practices, and lack of specific laws and regulations on e-waste. In order to address these issues the Thai government passed the National Strategic Plan on Integrated Management of WEEE (WEEE Strategic Plan) in July 2007. The strategy, which was approved by the cabinet on 24 July 2007, is a 10-year road map.

Vietnam. In Vietnam there are currently no laws or regulations dealing specifically with e-waste, although there are number of related decrees. Vietnam also lacks a sound inventory of e-waste. Nguyen et al., (2009) studied the e-waste flows of five large home appliances (televisions, refrigerators, washing machines, personal computers and air conditioners). They estimated that Vietnam would discard about 3.86 million appliances or 114,000 tonnes in 2010, and 17.2 million appliances or 567,000 tonnes in 2025. Another study conducted by URENCO Vietnam at the request of Ministry of Natural Resources and Environment (MONRE) estimated the e-waste quantities as shown in Table 8.

Malaysia. An e-waste inventory for Malaysia was conducted in 2008 with funding from Ministry of Environment, Japan. This study found that Malaysia generated 1.1 million tonnes of e-waste in 2008, (Department of Environment Malaysia, 2008). E-waste has been regulated in Malaysia since 2005. The Department of Environment (DOE) within the Ministry of Natural Resources and the Environment (NRE) is responsible for the planning and enforcement of regulatory requirements related to e-waste. Although there are no direct regulations dealing with e-waste, the management of e-waste is incorporated in the Environmental Quality (Scheduled Waste) Regulations 2005 and the Environmental Quality (Prescribed Premises) (Treatment, Disposal Facilities for Scheduled Waste) Regulations, 1989 (control of

Table 8. Estimated generation of e-waste from various sources in Vietnam.

Source	Units (2006)	Units (2020)	% increase
Televisions	364,684	4,852,039	1230
Computers	131,536	1,444,038	1000
Mobile phones	505,268	3,533,465	600
Refrigerators	230,856	2,267,318	880
Air conditioners	49,782	873,163	1650
Washing machines	327,649	2,625,882	700

Source: (URENCO Environment, 2007).

collection, treatment, recycling and disposal of scheduled waste, including e-waste). In January 2008, the DOE issued the 'Guidelines for Classification of Used Electrical and Electronic Equipment in Malaysia' for assisting all stakeholders involved in e-waste management in identifying and classifying used products according to the regulatory codes. The guideline provides a list of the types of electrical and electronic waste which may contain the hazardous compounds or materials.

Sri Lanka. The authority responsible for managing e-waste in Sri Lanka is the Central Environmental Authority (CEA) under the Ministry of Environment and Natural Resources (MENR). Sri Lanka has well-established legislation for environmental protection, and some of the laws and regulations dating back to over a century. The National Environment Act (NEA), enacted for protecting and managing the environment, endorsed the formation of the CEA in 1981. The NEA also has prescribed regulations for the management of hazardous waste. The CEA has also prepared Guidelines for the Implementation of Hazardous Waste Management Regulations.

At the sixth meeting of the Conference of the Parties to the Basel Convention (COP 6), the MNER signed a Memorandum of Understanding with the Basel Convention to implement a project on 'Development of National Implementation Plan for Electrical & Electronic waste in Sri Lanka', which forms one component of the Pilot Project for the Environmentally Sound Management of E Waste in Asia and the Pacific. The project comprises six phases: preparation of an inventory of selected electronic and electrical products; training and awareness raising; and implementation of three pilot projects in three provinces based on the outcome of the field survey. The first component of the project is now completed; it broadly covered a desktop study and field surveys to prepare inventories of selected products (computers, printers, televisions, mobile phone, refrigerators, washing machines). The main outcomes of the first phase of the project were the establishment of a coordination mechanism, establishment of a Project Control Unit (PCU), preparation of a detailed inventory for the selected products, conduction of field surveys, awareness-raising workshops and stakeholder consultation. The study highlighted the need to develop a regulatory framework to facilitate an effective e-waste management system with an understanding of global regulations, such as the WEEE RoHS Directives, and extended producer responsibility schemes. The study also found that the current computer market size in Sri Lanka is 300,000 units per year, with an annual growth rate of 08–10%. Similar data was found for printers (130,000; growth: 5–7%), televisions (350,000–400,000; growth: 6–8%), mobile phones (1.0–1.2 million), refrigerators (250,000–275,000; growth: 4–6%) and air conditioners (40,000–50,000; growth: 4–6%) (Central Environment Authority Sri Lanka, 2008).

Also in 2010, the CEA launched the National E-waste Programme for manufacturers, importers and brand-owners to set up a collecting mechanism for e-waste. Accordingly, importers of electronic consumer durables were required to sign a Memorandum of Understanding with the CEA to collect and dispose of e-waste. At present, there are 14 partner organizations in this programme.

Conclusions

E-waste is being generated around the world at a higher rate than most other waste streams. Although a number of initiatives have been implemented to achieve ESM of e-waste, there are a significant number of issues and challenges to deal with. Cooperation among the key stakeholders is the key to finding solutions to the above issues and challenges. Although there are currently a number of activities conducted by various countries and donor agencies, harmonisation of these activities is needed to maximise the limited resources.

Developing countries, especially in Asia and Africa, are experiencing a major problem with the ever-increasing amount of e-waste, as they lack the policies and infrastructure to deal with the issue in a sustainable way. Although e-waste is a problem because of its hazardous components, it is also a solution to the depletion of the natural resources that manufacturers of EEE depend on. Proper recycling of e-waste is of great importance in order to harvest these secondary sources. The e-waste recycling chain consists of three main steps: collection, sorting/dismantling, and pre-processing and end-processing. In developing countries these three activities are undertaken predominantly by the informal e-waste recycling sector, with little presence of the formal recycling sector. Although the first two of these steps can be undertaken by the informal sector without much environmental impact, the last step of end-processing, when undertaken by the informal recycling sector, could result in severe environmental impacts.

The transfer of appropriate technology to developing countries to manage their e-waste problem should be undertaken, keeping in mind their social, environmental and economic boundaries. Direct transfer of technology without any consideration given to inter-linked, non-technical aspects has led to failure in a number of cases. The collection of e-waste by the informal sector is quite efficient in a number of developing countries. Furthermore, the informal sector is quite active in the pre-processing stage of recycling operations. For example, deep-level manual dismantling of used EEE in developing countries may be preferred over high-technology, automatic processes as a result of an abundant workforce and low labour costs. Deep-level manual dismantling also results in good preparation of feedstock for the subsequent steps in the recycling process. However, there is lot of room for improvement in all other informal recycling activities through technology transfer. Even with such improvements, an optimal level will be reached whereby it will no longer be feasible for informal recyclers to process materials efficiently. State-of-the art end-processing facilities, such as integrated smelters, will be required to recover precious materials in an efficient way. The problem is that most developing countries cannot afford the high investments for such technology, with the exception of large emerging economies or highly industrialised countries within the region. Therefore, a regional approach is more appropriate at the latter stages of end-processing of e-waste.

The future success of technology transfer to countries with dominant and successful informal e-waste recycling sectors will depend on innovative models whereby the informal sectors are still allowed to participate in safe recycling practices while hazardous operations are transferred to state-of-the-art formal recyclers. Such models would require giving a high priority to further improvement of collection and pre-processing by the informal sector through technology transfer to benefit state-of-the art formal recycling operations towards the end of the recycling chain.

EPR is considered globally as one of the most powerful policy mechanisms in dealing with the e-waste problem. Most developed countries have had a lot of success implementing EPR-related policies. Owing to the urgency of the issue, a number of developing countries are planning or have already adopted EPR-related policy mechanisms based upon the templates used in developed countries. If possible, developing countries should take care to avoid this path and try and attempt to design their own EPR schemes based upon their capacity to implement such schemes.

Whichever scheme is adopted, managing e-waste is a major challenge to an individual country in the developing world owing to the limitations and challenges discussed in this article. As such, serious consideration should be given to a regional approach, where economies of scale may be more appropriate.

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