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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 in many countries around the world. In particular, developing countries face 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 due to 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 in 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 paper 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

1 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, e-waste is growing at a rate of 3-5% 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 many electronic items used around the world today. Table 1 below shows the estimated life span of some commonly used electronic items.

Table 1: Estimated lifespan and weight of electrical and electronic equipment (EEE) Source: UNEP and UNU (2009)

Equipment	Life span in years	Mean Weight (kg)
Personal computer & Monitor	5 to 8	25
Laptop	5-8	5
Printer	5	8
Mobile Phone	4	0.1
Television	8	30
Refrigerator	10	45

In the United States, where it is believed to produce the largest amounts 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 European Union (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, 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 thataround 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 every year (Deathe et al, 2008) 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 hand held electronic items used in the present society. Each year over 130 million mobile phones in the United States and over 105 million mobile phones in Europe reach their end-of-life and are thrown away (Canning, 2006). As a result used Electronic and Electrical Equipment (EEE), commonly known as e-waste, also known as WEEE (Waste Electrical and Electronic Equipment) have become a serious social problem and an environmental threat to many countries worldwide. United Nations estimate that collectively the world generates 20 to 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 latest report released by the United Nations (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 from 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 higher in India. The report also cites that in the United States more than 150 million mobiles and pagers were sold in 2008, up from 90 million five years before and 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 to 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 ESM of e-waste resulting in adverse socio-economic, public health and environmental impact of toxics in e-waste. This paper aims to present a review of challenges and issues faced by Asian countries in managing their e-waste in a sustainable way.

2 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 their 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 estimated life span of 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 homes and offices, thus, making the estimation a challenging task. (Ongondo *et al.*, 2011) summarises some of the available e-waste data/estimates from different sources (Table 2).

Table 2: Global generation of e-waste

Country	E-waste generation (tonnes/year)	Per capita generation (kg/person)
Germany	1,100,000 (2005)	13.3
United Kingdom	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
United States	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.

3 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 European Union as below:

"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, toys etc., basically covering most of the small and large appliances used in households and business in the modern society. The Table 3 below summarises the main categories of e-waste as defined by the European Union's Revised WEEE Directive (explained later in section 5.1).

Table 3: 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 equioment containing screens having a surface greater than 100 cm2	Screens, televisions, LCD photo frames, monitors, laptops, notebooks
Lamps	Straight fluorescent lamps, compact fluorescent lamps, fluorescent lamps, high density discharge lamps, low pressure sodium lamps, LED
Large equipment (any external dimension greater than 50 cm)	Washing machines, cloths 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 50cm)	Vaccum 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 IT and telecommunication equipment (no external dimension more than 50 cm)	Mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones

4 Problems and opportunities associated with e-waste

4.1 Description of problems

Problems associated with e-waste are becoming well known in the scientific literature. In general WEEE is a complicated assembly of significant number of different materials, many of which are highly toxic. For example, the production of semiconductors, printed circuit boards, disk drives and monitors used in computer manufacture utilises many hazardous chemicals. Computer Central Processing Unit (CPU) contains 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 (Pb) is mainly used in cathode ray tubes (CRTs) in monitors, tin-lead solders, cabling, printed circuit boards 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 printed circuit boards, connectors, covers and cables. There is growing body of literature suggesting that BFRs have negative environmental and health effects hence be limited or replaced altogether (Barontini & Cozzani, 2006); (Birnbaum & Staskal, 2004); and (Herat, 2008a). Exposure of PBDEs to personnel working in e-waste recycling facilities and people in surrounding areas has been studied by researchers worldwide including (Cai & Jiang, 2006); (Jakobsson *et al.*, 2002); (Julander *et al.*, 2005); (Leung *et al.*, 2006); (Leung *et al.*, 2007); (Pettersson-Julander *et al.*, 2004); (Sjodin *et al.*, 2001);(Tue *et al.*, 2010a); (Han *et al.*, 2009); (Wang *et al.*, 2009a) and (Liu *et al.*, 2009). PBDEs are also found in the environment around some e-waste recycling facilities. A study conducted by Sepulveda 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 compared to other industrial or urban areas.

4.2 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 is also a global issues. Figure 1 below shows that metals count to nearly 60% of the e-waste stream and Table 4 shows the use of certain valuable metals in the WEEE manufacture.

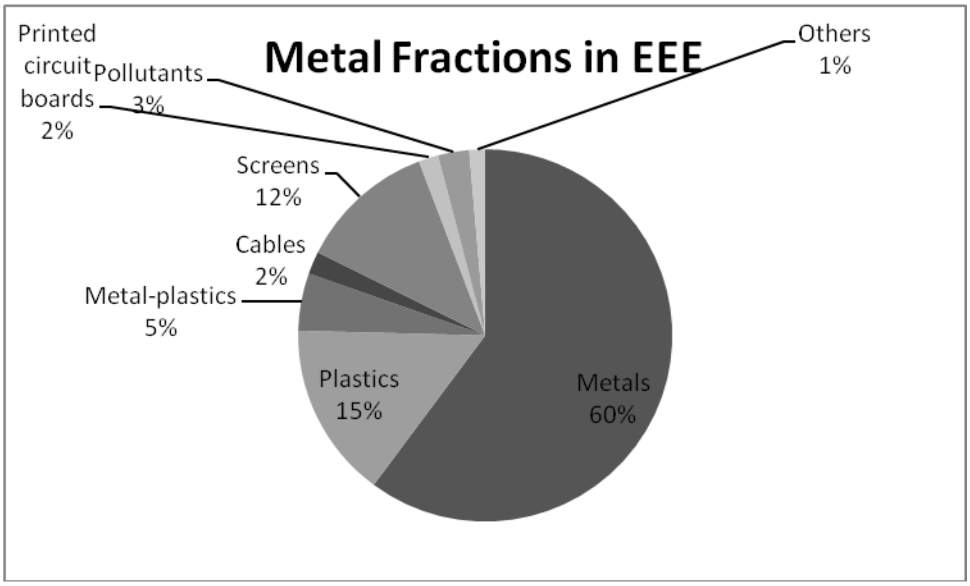

Figure 1: Metal fraction in electrical and electronic equipment (WEEE)
Source: (Widmer *et al.*, 2005)

Table 4: Metals used for electric and electronic equipment (EEE) manufacture
Source: UNEP and UNU (2007).

Metal	Annual Production Tonnes (2006)	Demand for EEE Tonnes/y	Demand/Production %
Silver	20,000	6,000	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	5,600	900	16
Selenium	1,400	240	17
Indium	480	380	79

The above discussion shows that although e-waste is seen as a problem, it is also important to find effective ways to recover the resources contained in them.

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

5.1 *E-waste Regulations in the European Union*

5.1.1 *Waste Electrical and Electronic Equipment (WEEE) Directive*

The aim of the WEEE Directive is to minimise the impact of electrical and electronic goods on the environment, by increasing re-use 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 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 by 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 4 years of operation of the WEEE Directive, only about a third of e-waste was treated in line with these laws and the other two thirds is going to landfill and potentially to sub-standard treatment sites outside the European Union. As a result the WEEE Directive was revised in late December 2011. The revised WEEE directive requires by 2016, all member states will need to collect 45% of the EEE put on the market, increasing to 65% in 2019. .

5.1.2 *Restriction of Hazardous Substances (RoHS) Directive*

The Restriction of Hazardous Substances (RoHS) Directive was created by the European Parliament in 2003 recognising the fact that not all hazardous substances in WEEE can be recycled or disposed of in an environmentally sound manner, thus imposing a ban on the use of certain substances in electrical and electronic equipment. 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 July 1st. It names six substances of immediate concern: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and ploybrominated diphenyl ethers (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 4 years (European Union, 2003a).

5.2 E-waste Regulations in Japan

Japanese government has formulated two laws to deal with the e-waste situation 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 cloths 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 manufactuers. When disposing home appliances consumers are required to pay for cost of transportation and recycling. Recycling fees range from 2400 yen (washing machines) to 4600 yen (refrigerators). Manufactuers 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 Law for the Effective Utilisation of Resources 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).

5.3 E-waste Regulations in China

China is considered to be one of the fastest growing economies in the world and the largest exporter of information and communication technology products to the world surpassing Japan, European Union and United States. It is also estimated that total amount of e-waste generated in China is around 1.11 million tonnes per year mainly coming 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 by employing over 0.7 million people in 2007 of which 98% 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) estimates that total amount of e-waste generated in China in 2003 was 55.9 million Units and predicted to increase that amount to 105.3 million (3.3 million tonnes) by 2010. (Li & Wong, 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 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) published in 2002 through a now well known document ‘Exporting Harm: The High-Tech Trashing of Asia’. This report asserts that 50 to 80 % of e-waste collected for recycling in the United States is exported to developing nations (Puckett *et al.*, 2002).

In order to address the problem of e-waste, the Chinese government undertook number of measures including prohibiting the import of e-waste and other hazardous waste since 2000, 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 is in force since 2006. Also recently, China introduced a licensing scheme for proper e-waste recycling and in that process prohibiting informal recycling by unauthorised recycling firms (Jinhui Li *et al.*, 2011).

China's problem with e-waste has come about mainly due to 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 legalize the management of waste electrical and electronic products and promote the comprehensive utilization of resources and development of circular economy as well as protecting environment, on March 5, 2009 the State Council adopted and promulgated the " *Administration Regulation for the Collection and Treatment of Waste Electrical and Electronic Products*", namely China WEEE. The regulations came into effect on 1st January 2011. The new regulation consists of 5 Chapters and 35 Articles. The Article 4 allows for 'Catalog for Disposal of Waste Electrical and Electronic Products' (a 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. The 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 district division, is authorized 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 could be found in (Chung & Zhang, 2011).

5.4 E-waste Regulations in India

In India e-waste is a major issue due 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 to the world average of 181% increase during this period (Sinha-Khetriwal *et al.*, 2005). A study conducted by (Dwivedy & Mittal, 2010) on future trends in computer waste generation in India have estimated 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 – 3,30,000 tonnes and is expected to reach 4,70,000 tonnes by year 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 to reach 800,000 tonnes by 2012 (Rathore *et al.*, 2011). The same study also estimate that India adds 15 million mobile 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 environmentally sound management 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 to take effect from 1st 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.

5.5 E-waste Regulations in the United States

It is widely known that the United States (US) is one of the largest producers of e-waste in the world. According one estimate in year 2000, US generated 2.2 million tonnes on 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 & Tierney, 2006). The US Government Accountability Office (GAO) reports that over 100 million computers, monitors and televisions become obsolete in the US 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 cathode ray tube (CRT) technology is rapidly 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, the 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. 13 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 in general have settled for an extended producer responsibility systems where costs are borne by the manufacturer or retailer (Townsend, 2011) .

During the summer in 2011, 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 United States. 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 its used electronics and also to encourage the growth of the U.S. electronics recycling industry (US EPA, 2011).

5.6 E-waste regulations in Australia

The Australian Government recently reported that in 2007/08, 31.7 million new televisions, computers and computer products were sold in Australia. Also during this period 16.8 million units of this equipment reached their end of life with 88% of them sent to landfill and only 9% recycled. The Government also estimates that number of televisions, computers and computer products reaching their end of life is expected to grow to 44 million by 2027/28. Australian state and federal governments are currently working together to impose regulations directed towards extended producer responsibility upon computer manufacturers and retailers with a view to managing this huge and growing waste stream (EPHC, 2010).

To fulfil 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 2012-13 and increasing to 80% of waste arising in 2021-22. The scheme also includes a material recovery target of 90 per cent, which will come into effect in the 2014-15. 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.

5.7 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 the human health and the environment from adverse impacts resulting from the generation, management, transboundary movements and disposal of hazardous and toxic wastes. It entered into force on 5 May 1992 in accordance with article 25(1) of the Convention. As at September 2010 there are 178 parties to the Convention.

The Basel Convention's Conference of the Parties (COP) has made several decisions to achieve environmentally sound management of electrical and electronic waste. Commencing from its 6th meeting (COP6) in December 2002 where it identified electronic wastes as a priority waste stream in the strategic plan for the implementation of the Basel Convention to 2010. In 2006 Basel Convention's 8th meeting of the Conference of the Parties (COP8) was held in Nairobi on 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). Basel Convention has conducted number of workshops on environmentally sound management of e-waste in the Asia Pacific region, the latest one 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 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 environmentally sound management. A guidance document on the environmentally sound management of used and end-of-life mobile phone was adopted by the 8th 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)

5.8 *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 in 2003 proposed the development of the 'Asian Network for Prevention of Illegal Transboundary Movement of Hazardous Wastes'. The network aims at facilitating the exchange and dissemination of information on transboundary movements of hazardous wastes and selected used products among the North-East and South-East 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 re-use 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-tech 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, six G8 countries and eight international organisations participated, progress and issues related to environmentally sound management 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 UNCRD website (http://www.uncrd.or.jp/)

6 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, at times also refer to as cleaner production, as a result of major regulatory changes that have and are taking place internationally and together with pressure from end-users, 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 has 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 towards providing information on product stewardship and extended producer responsibility (EPR) and guidance on public procurement with a view to improving environmental performance. Table 5 below shows some possible approaches to EPR with some examples.

Table 5: Some approaches to EPR and related examples
Source: Widmer et al., (2005).

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

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

7.1 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. Informal recycling sector is very active in 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.

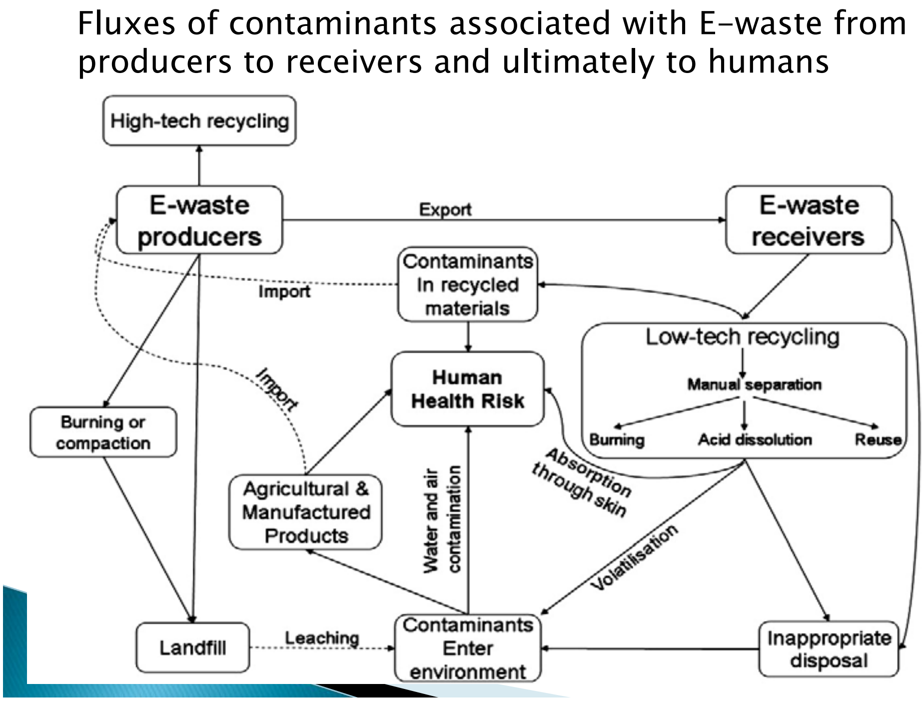

Figure 2. Health risk implications of WEEE

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 number of e-waste recycling sites in China and India found very high levels of lead, PBDEs, PCDD/Fs and 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 DEHP [Bis(2-ethylhexyl)phthalate] and DBP (Dibutyl phthalate) 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 the e-waste recycling facilities respectively and found very similar results confirming the previous studies. Tables 6, 7 and 8 below report on research undertaken to assess the impacts on e-waste recycling in developing countries on the sediments, humans and biota respectively.

Table 6: 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 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	Jinhui Li et al., 2011
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 vegetations near an e-waste recycling site in South China	(Wang *et al.*, 2005), (Wang *et al.*, 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, Leung et al, 2007
Trace metal contamination of sediments in an e-waste processing village in China	(Wong *et al.*, 2007)

Table 7: 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 placenta 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	(Wang *et al.*,

of heavy metals around an e-waste dismantling site located in Taizhou	2010)
Assessment of cadmium exposure for neonates in Guiyu e-waste pollution site	(Li *et al.*, 2011)
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 hormorne 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)

Table 8: 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), (Luo *et al.*, 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)

Table 6 summarises the studies undertaken near in Nanguan River which runs through an e-waste recycling area of Taizhou in East China to investigate the impacts of heavy metals, PCBs, 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 to 2990 ng/g dw exceeding the Canadian freshwater sediment quality guideline of 34 ng/g dw by nearly 20-90 times. Further investigation into 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 global mean (5.4 µg/kg) (Tang *et al*, 2010a). Similar findings were noted for PAHs where levels ranged 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 to the China's environmental quality standard for soils Pb(13 times), Cd (50 times), Zn (35 times) and Cu (363 times) (Li et al 2011). 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 underetaken to investigate the impacts of heavy metals on humans living near e-waste recycling sites as summarised in Table 7. Concentration of Pb, Cd, Cr and Ni in human placenta in women living near Guiyu in China revealed 41.6% women has Pd levels exceeding 500 ng/g wt compared to 24.4% women in control site (Guo et al , 2010). Similar result was found for Cd near an e-waste recycling site in China where unrinary Cd levels were found to be significantly high (0.72 µg/L) compared to the control site (0.27 µg/L) (Wang et al 2011a). Number of studies have also confirmed high levels of PCBs and PBDEs in humans living near e-waste recycling sites. A investigation into concentrations of PCBs and PBDEs in the blood of children living near an e-waste recycling plant China revealed high concentrations of PCBs (484 ng/g compared to control area 255 ng/g) and PBDEs (664 ng/g compared to control area 376 ng/g) (Han et al, 2011). 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 fro workers at an e-waste recycling plant in Eastern China has revealed concentrations of PBDEs ranging from 22.8-1020 ng/g dw (3 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).

7.2 Issues and challenges for environmentally sound management (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 paper large amounts of e-waste are currently being exported to developing countries for the purpose of re-use, 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 impact occur during open burning on e-waste to recover precious metals. In spite of these significant environmental and health impacts, the 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.

Figure 3. Transboundary movement route of WEEE
(Source: Silicon Valley Toxic Coalition)

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 are rare to find. As a result most of the e-waste is managed by 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 the e-waste volumes, copper wires to salvage valuable metals such as copper and acid leaching to recover precious metals from the printed circuit boards.

Part of the problems faced by developing countries is due to 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 to policy makers. For example (Kojima *et al.*, 2009) in their study into applying EPR policies in e-waste recycling in China and Thailand found two major difficulties to implement EPR in developing countries. The first difficulty is for the governments to collect 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 the 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 sector to gain access to e-waste.

In many developing countries there is a trend where used WEEE flows from the cities to the countryside due to 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 even the task is assigned to producers and importers, the collection of used WEEE becomes very difficult. It is also difficult to assign the 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 & Nnorom, 2007) have summarised following as the key challenges facing developing countries towards 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 them 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

7.3 Policy approaches in managing e-waste in Asian countries

As seen from above there are numerous challenges to overcome before the developing countries achieve ESM of e-waste. Number of workshops and studies has been conducted by organisations such as Basel Convention to investigate the obstacles in developing countries to adopt 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 due to the urgency of the issue, number of developing countries are looking into adopt policies and technologies that are already been implemented in developed countries where proper infrastructure is in place to manage e-waste. However, the economic, environmental and social situation in number of these developing countries (mainly located in Asia and Africa) are different to the developed world, hence, the need for adapting, implementing, and scaling up appropriate technologies that are more suited to the local conditions. One of the key areas that developing countries need to concentrate 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 they lead to high collection rates and many economical and social benefits to the poor section 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 more economic and social benefits to poor community. The last stage of the e-waste recycling chain where processes/techniques are necessary to extract the valuable components such as metals is where the current environmental impacts are. Most of the informal recyclers utilise low efficiency processes resulting 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 the policy makers in developing countries is how to achieve efficiencies in the informal sector at the same time 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 due to the fact that informal recycling is undertaken by the poor people and as such the government is unable to impose heavy fines as they cannot pay it. 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 & Managi, 2010) argues 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 governments of developing countries are unable to impose fines on e-waste disposers of developed countries where most of the e-waste comes from. One solution is for the governments in developing countries to co-orporate with governments of importing countries to impose fine on noncompliant exporters. (Chi *et al.*, 2011) argues 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 the social reality and predicted that informal sector may remain an influential recycling force for years to come. They suggested the whole informal recycling chain must be thoroughly investigated on 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-tech, capital intensive e-waste recycling processes adopted in highly industrialised countries may not be suitable for certain developing countries. Instead, low-tech, labour intensive e-waste recycling processes may satisfy all the above objectives, hence, more potential for success. 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) cites major pilot scale e-waste recycling project in China and shows how a fully financed state-of-art e-waste recycling plant can fail when not supported by a proper collection network and by the competition from informal sector. The study found that transfer of technology to e-waste recycling plants without taking into 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 failure of such projects.

Financing

Financing the e-waste collection schemes and allocating the 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 (Kojima *et al.*, 2009) in their study into applying EPR policies in e-waste recycling in China and Thailand found two major difficulties to implement EPR in developing countries. The first difficulty is for the governments to collect funds from producers or imports if the goods are smuggled into the country or if the small shop-assembled products have a large share of the market. The second difficulty is the 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 sector to gain access to e-waste. (Agamuthu & 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 on EPR regulations, (Akenji *et al.*, 2011) have proposed that developing countries should move gradually 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 the governments.

7.4 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 the issues related to e-waste (Ahmed, 2011).

Currently there is no inventory of e-waste in Bangladesh. (Environment and Social Development Organisation, 2010) estimates that every year Bangladesh produces about 2.8 million tonnes of e-waste out of which 2.5 million is contributed by the e-waste generated 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 scraped 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, mainly undertaken by the informal sector. Most of the e-waste in Bangladesh is dumped in open landfills, farming land and open water bodies causing severe health and environmental impacts. (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 and 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 Pakistan currently has 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 the environmental protection and movement of chemicals and waste. There is no formal mechanism to manage e-waste at national level. Therefore, people use different methods to manage e-waste locally. Informal recycling sector is very active where number of workers, including children, earns their living my dismantling the electronic scrap and extracting valuable metals. Open burning and open dumping of e-waste is very common in Pakistan.

Thailand

Thailand generated about 80,000 tons/year of e-waste expected in 2009, out of which electrical and electronic manufacturers generated about 20,000 tons/year. Also it was 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 2,000 electrical and electronic manufacturers making it one of the largest manufacturers in the region. In addition Thailand also had 9,000 junk shops and 30 formal e-waste recycling facilities as at 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 environmental sound management practices and lack of specific laws and regulations on e-waste. In order to address these issues the Thailand 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

Currently in Vietnam there are no laws and regulations specifically dealing 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 9 below.

Table 9: Estimated generation of e-waste from various sources in Vietnam
Source: (URENCO Environment, 2007).

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%

Malaysia

An e-waste inventory for Malaysia was conducted in 2008 under the 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 to deal with e-waste, the management of e-waste is incorporated within the Environmental Quality (Scheduled Waste) Regulations 2005 and the Environmental Quality (Prescribed Premises) (Treatment, Disposal Facilities for Scheduled Waste) Regulations, 1989 (control on collection, treatment, recycling and disposal of scheduled waste including e-waste). In January 2008, the Department of Environment (DOE) issued the ‘Guidelines for Classification of Used Electrical and Electronic Equipment in Malaysia’ for assisting all stakeholders involved in e-waste management to identify and classify the 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 environment 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 CEA in 1981. NEA also has prescribed regulations for the management of hazardous waste. CEA has also prepared Guidelines for the Implementation of Hazardous Waste Management Regulations.

At the 6th meeting of the Conference of the Parties to the Basel Convention COP 6), the MNER signed an 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 of 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 which 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 was establishment of a coordination mechanism, establishment of a Project Control Unit (PCU), preparation of a detailed inventory for the selected products, conducting field surveys, awareness raising workshops and stakeholder consultation. The study highlighted need to develop a regulatory framework to facilitate an effective e-waste management system with an understanding of global regulations such as WEEE Directive and RoHS Directive and extended producer responsibility schemes. The study also found that 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 and growth of 5-7%), televisions (350,000-400,000 and growth 6-8%), mobile phones (1.0-1.2 million), refrigerators (250,000-275,000 with growth 4-6%) and air conditioners (40,000-50,000 with 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.

8 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 environmentally sound management of e-waste, there are 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 currently there are 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 due to its hazardous components, it is also a solution to the depletion of the natural resources which the manufacture of EEE depends upon. 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 all these three activities are predominantly undertaken by the informal e-waste recycling sector with a 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 its social, environmental and economic boundaries. Direct transfer of technology without any consideration given to inter-linked, non-technical aspects has led to failure in number of cases. The collection of e-waste by the informal sector is quite efficient in number of developing countries. Further, the informal sector is quite active in the pre-processing stage of the recycling operations. For example, deep level manual dismantling of used EEE in developing countries may be preferred over high-tech automatic processes due to 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 reach whereby it will not be feasible anymore for the informal recyclers to process the materials efficiently. The state-of-the art end processing facilities such as integrated smelters would be now required to recover the precious materials in an efficient way. The problem is that most of the developing countries cannot afford the high investments for such technology except for 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 sector will depend on innovative models where by informal sector is allowed to still participate in safe recycling practices while the hazardous operations transferred to state-of-art formal recyclers. Such models would require high priority given to further improve the collection and pre-processing by the informal sector through technology transfer to benefit the 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 to deal with the e-waste problem. Most developed countries have had lot of success on implementing EPR related policies. Due to the urgency of the issue, a number of developing countries are planning/or already adopted EPR related policy mechanisms based upon the templates used in developing countries. If possible, the 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 deloping world due to number of limitations and challenges discussed in this paper. As such, a serious consideration should be given to a regional approach where economies of the scale could become more appropriate.

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