THE EFFECTIVENESS OF ELECTRICAL AND ELECTRONIC WASTE RECYCLING AND ITS IMPLICATIONS TO GREEN BUILDING: Empirical Studies in India and Switzerland

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ABSTRACT

The life of consumer electrical and electronic (E&E) devices is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities. This creates a large waste stream of obsolete E&E equipment. Even though there are conventional disposal methods for E&E waste, these methods have disadvantages from both economic and environmental viewpoints. This paper examines the existing recycling situations and collection methods of E&E waste in India and Switzerland. Questionnaire survey, interview discussions and case studies are conducted. Their E&E waste scenario and technologies applied for E&E waste are investigated. It is found that India performs better in E&E intensity per service unit and employment potentials, while Switzerland performs better in occupational hazards and emissions of toxics. Recommendations to improve the existing E&E waste recycling situations and its implications to green building are also given.

KEYWORDS

electrical and electronic waste, waste management, recycling, India, Switzerland

INTRODUCTION

Waste includes domestic waste, E&E waste, commercial waste and industrial waste. E&E equipment is used for data processing, telecommunications or entertainment in private households and businesses, which includes computers, entertainment electronics and mobile phones (Hage, 2007). E&E waste is the E&E equipment that has been discarded by their original users. Despite its common classification as a waste, disposed of electronics are considerable categories of secondary resource due to their significant suitability for direct reuse, refurbishing, and material recycling of its constituent raw materials. Reconceptualization of E&E waste as a resource thus pre-empts its potentially hazardous qualities.

The production of E&E equipment is increasing worldwide. Both technological innovation and market expansion continue to accelerate the replacement of equipment leading to

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a significant increase of E&E waste. E&E waste is recognized as the fastest growing waste stream among other types of waste, with estimates of about 14 to 20 kg per person per annum (Darby and Obara, 2005), and it is increasing at about three times higher than the average of municipal waste. Currently, E&E waste accounts for about 8% of all municipal waste (Darby and Obara, 2005).

E&E waste may cause environmental problems due to its hazardous material contents, which poses a significant threat to human health and the ecosystem. E&E waste is both valuable as source for secondary raw materials, and toxic if improperly treated and discarded. E&E waste is more toxic than normal household garbage. E&E devices contain toxic heavy metals, including arsenic, antimony, beryllium, cadmium, chromium, copper, lead, mercury, nickel and zinc. It is estimated that about 40% of all heavy metals in household garbage comes from E&E equipment (Tasaki *et al.*, 2006). Although metals, glass and plastic in E&E equipment are recyclable, more than 70% or 3.2 million tonnes of E&E waste stream ends up in landfills (Darby and Obara, 2005). Rapid technology change, low initial cost and even planned obsolescence have resulted in a fast growing problem around the world. Technical solutions are available but in most cases a legal framework, a collection system, logistics and other services need to be implemented before a technical solution applied.

Bangalore in India and Guiyu in Shantou region of China have E&E waste processing facilitates (Hicks *et al.*, 2005; Wong *et al.*, 2007). E&E waste is being sent to these countries for processing, however, in most cases illegally. Uncontrolled burning and disposal are causing serious environmental problems due to the methods of processing waste. Similar threats are found in many other components.

Currently, E&E waste management systems in developing countries are characterized by processes that expose workers to toxins, degrade the local environment and ineffectively recover resources. Recycling E&E waste is an important issue, not only from the point of waste treatment, but also from the aspect of recovering valuable materials. Waste management activities can be summarized as (Hage, 2007; Tam and Tam, 2006; Tam *et al.*, 2005): i) collection; ii) reception; iii) sorting; iv) recovery of materials; v) biological treatment of organic materials; vi) thermal treatment; and vii) landfill.

In 1991, the first E&E waste recycling system was implemented in Switzerland beginning with the collection of refrigerators. Over the years, all other E&E devices were gradually added to the system. Legislation followed in 1998 and since January 2005 (Hage, 2007), it has been possible to return all E&E waste to the sales points and other collection points free of charge. There are two established producer responsibility organizations to handle electronic waste and electrical appliances. The total amount of recycled E&E waste exceeds 10kg per capita per year (Hage, 2007).

It should be highlighted that several difficulties in restricting environmental threats for E&E waste are (Darby and Obara, 2005; Datta, 2000; Hage, 2007; Shen and Tam, 2002; Tam and Tam, 2006; Tam *et al.*, 2006; Tam *et al.*, 2005): i) there is a lack of awareness by the public about toxins in E&E components and proper disposal; ii) laws are not in place to protect the environment for E&E waste; iii) computer refurbishing centres are limited; iv) E&E waste recycling centres are absent; and v) take-back programs for computers are not available through consumer organizations or vendors.

Therefore, this paper focuses on the following objectives:

- To examine E&E waste generation;
- To investigate E&E waste recycling methods;
- To conduct empirical studies in India and Switzerland on their existing recycling practice and technologies used for E&E waste recycling; and
- To recommend methods rectifying problems encountered in waste recycling and to efficiently and effectively implement E&E waste recycling.

ELECTRICAL AND ELECTRONIC WASTE GENERATION

Millions of tonnes of E&E waste from obsolete computers and other electronics, are generated, which constitutes to a substantial percentage of solid waste stream and is rapidly growing (Tasaki *et al.,* 2006). Figure 1 shows the numbers of personal computer shipped and obsolete between 1997 and 2005. It should be highlighted that it is more than double of the personal computer units used in 2005 than in 1997.

Due to the result of technology development and high standards for personal computers, the lifespan of personal computer is getting shorter than ten years ago. Figure 2 shows that the average lifespan of a personal computer in 1992 was 4.5 years, but this value was decrease to only 3 years in 1998 and is further decreased to 2 years in 2006.

FIGURE 1. Shipped and obsolete personal computers (Darby and Obara, 2005).

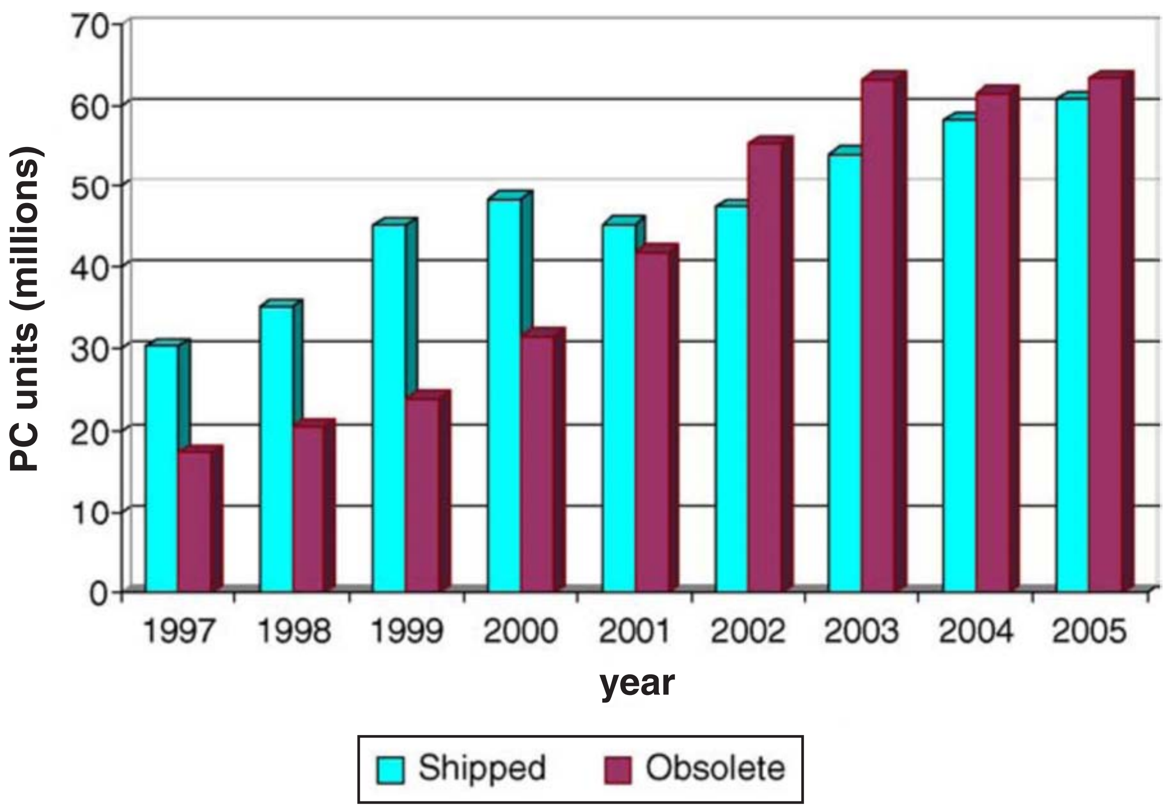
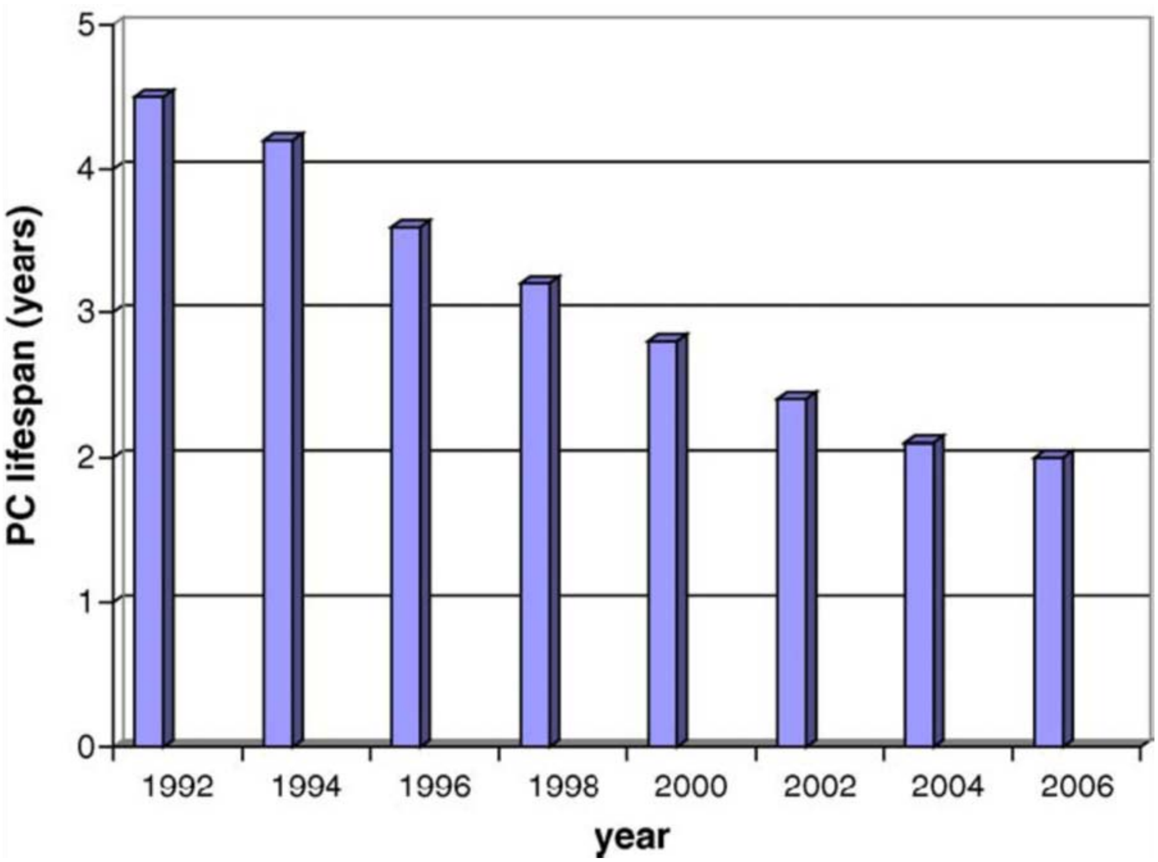


FIGURE 2. Average lifespan of personal computers (Darby and Obara, 2005).



ELECTRICAL AND ELECTRONIC WASTE HANDLING

Incineration

Incineration is a method of disposing waste by burning it (Lee *et al.*, 2007). Incineration usually functions as an alternative to other disposal methods, especially landfilling. Incineration can reduce the overall volume of waste stream and, especially for hazardous waste. It is intended to reduce waste toxicity and other hazardous characteristics. It is particularly popular in countries such as Japan where land is a scarce resource (Jung *et al.*, 2004; Okubo *et al.*, 2007).

Open Burning

Since open fires burn at relatively low temperatures, it releases more pollutants than in a controlled incineration process at an incineration plant (Callan and Thomas, 2006). Inhalation of open fire emissions can trigger asthma attacks, respiratory infections, and cause other problems such as coughing, wheezing, chest pain, and eye irritation. Chronic exposure to open fire emissions may lead to diseases such as emphysema and cancer. For example, burning premature ventricular contraction releases hydrogen chloride, which on inhalation mixes with water in the lungs to form hydrochloric acid. This can lead to corrosion of lung tissues, and several respiratory complications. Often open fires burn with a lack of oxygen, forming carbon monoxide, which poisons blood when inhaled. The residual particulate matter in the form of ash is prone to fly around the vicinity and can also be dangerous when inhaled.

Landfilling

Landfilling is one of the most widely used methods of waste disposal (Morf *et al.*, 2006; Tam *et al.*, 2004; Tam *et al.*, 2006; Tilford *et al.*, 2000). Landfill is a waste disposal site for the deposit of waste onto or into land, including internal waste disposal sites, and a permanent site, which is used for temporary storage of waste, but excluding transfer facilities.

ELECTRICAL AND ELECTRONIC WASTE RECYCLING METHODS

Material Recovery Facility Process

E&E waste transports to material recovery facilities (MRFs) for testing and sorting. The MRF process is the most critical step in E&E waste recycling (Lee *et al.*, 2007). The ultimate fate of the collected equipment is determined at the MRFs. In MRF processing, collected equipment can be divided into two categories, reusable or recyclable. The equipment and parts that can be reused are sorted which will eventually become either recycled or scrap materials. The important factors at this stage include the age of the equipment and its mechanical conditions to maximize economic values from the collected devices (Osibanjo and Nnorom, 2007). The steps of the MRF processing include (Darby and Obara, 2005): i) sorting; ii) size reduction; iii) vibrating screen; iv) magnetic separation; v) eddy current separation; vi) density separation; and vii) disposal.

Mechanical Recycling Process

Most commonly, mechanical recycling process is used to recycle plastics. The need to identify additives and contaminants is problematic. Also, to use the recycled plastics in high-end products, physical and mechanical properties of recovered resins must meet those of virgin resins. Plastics used in electronics have several characteristics. Acrylonitrile butadiene styrene and high-impact polystyrene provide good impact protections (Schlummer *et al.*, 2007). These resins are generally used in monitors and television for cathode ray tubes protection. Polyphenylene oxide has good properties at high temperature. Polyethylene and polyvinyl are excellent electrical insulators.

Due to the difficulty of working with materials of unknown composition, the market value of mixed or unsorted plastics is very low (Tam and Tam, 2006). To recycle plastics from discarded electronics, the first step is the sorting process. Contaminated plastics such as laminated and/or painted plastics must be removed. Different major resins are used in different electronic products and separation of plastics can provide a better recycling rate (Navarro *et al.*, 2007).

Depolymerisation and Conversion Process

For chemical recycling of plastics, several processes have been developed. One of these processes, was developed by the Association of Plastics Manufacturers in Europe (Association of Plastics Manufacturers in Europe, 2007). Metals are removed for processing. The remaining polymer chains from the depolymerisation unit are cracked at temperatures of about 350–450°C in the Hydrogenation Unit 1. The open carbon bonds are saturated by hydrogen because of high hydrogen pressure, more than 10 million N/m^2 (Association of Plastics Manufacturers in Europe, 2007). The liquid product goes through the distillation process. Any left-over inert material, which is not separated and removed in the depolymerisation step, and the unconverted plastic portion are collected in the bottom of the distillation column and removed as a residue, hydrogenation bitumen. The final high-quality products, off-gas and sync rude, are obtained by hydro treatment (Hydrogenation Unit 2). These final products are then sent to conventional petrochemical process (Iles, 2004).

Coke Oven Process

Coke oven process is essentially used for the carbonization of coal. The process conditions for carbonization in a coke oven are also suitable for recycling plastics, because at high temperature in a reducing atmosphere, charged plastics can thermally be decomposed without combustion. In a pre-treatment step, foreign materials including metal, glass and sand, are removed. The remaining plastic waste is then crushed and reduced in size, before being charged into a coke oven. This process involves high temperature and a reducing atmosphere. In the coking chamber, the waste plastics are heated to about 1200°C in an oxygen-free environment (Iles, 2004). The charged plastics are pyrolyzed at about 200–450°C, generate gas and are completely carbonized at about 500°C (Iles, 2004). The hydrocarbon oils and coke oven gas are refined from high-temperature gas generated by pyrolysis, and the residue is recovered as coke. The primary components of the product gas are methane and hydrogen.

RESEARCH METHODOLOGIES

To examine the existing E&E waste recycling situations, a questionnaire survey was conducted. The survey was sent to 500 parties including consultants, governmental departments and environmental professional associations in India and Switzerland. 306 had been received including 145 from India and 161 from Switzerland, with a response rate of about 61.2%. However, two of the questionnaires were not properly completed and only 304 questionnaires were valid.

After received the questionnaire responses, individual structured interviews were arranged with thirty respondents, selected from different business sectors: six from governmental departments, fifteen from environmental consultants, and nine from members of environmental professional associations. The interviews were intended to gather further comments; elaboration and interpretation on the results obtained from the questionnaire.

Case studies were also conducted to explore waste situations, recycling methods and recycling technologies applied in India and Switzerland.

RESULTS AND DISCUSSIONS

Table 1 summarises the survey results on the effectiveness of E&E waste recycling. For the respondents' background, it is found that about 25% and 28% of the respondents are from governmental departments, about 40% and 35% are consultants, and about 35% and 37% are from environmental professional associations in India and Switzerland respectively.

From the survey, about half of the respondents did not use recycling centers for recycling E&E waste, about 30% and 35% of the respondents from India and Switzerland respectively frequently use the centers and about 20% and 15% from India and Switzerland respectively rarely use the centers. This can highlight that many people are almost unaware or do not use the recycling centers. From the interview discussions, the interviewees explained that the locations of the centers in India are very inconvenience which requires at least one hour drive from the city, in which the locations did not bring encouragement for residents in recycling E&E equipment.

For the information of recycling center locations, about 40% and 52% of the respondents from India and Switzerland respectively get the information from internet service, about 20%

TABLE 1. Survey results on the effectiveness of E&E waste recycling.

	India	Switzerland
Respondents' background		
Governmental departments	25%	28%
Consultants	40%	35%
Environmental professional associations	35%	37%
Any recycling centers for recycling E&E waste?		
Frequently use the centers	30%	35%
Rarely use the centers	20%	15%
No	50%	50%
Information of recycling center locations		
From internet service	40%	52%
From directories	20%	18%
From local government advertisements and promotions	30%	27%
From relatives and friends	10%	3%
Types of E&E equipment recycling		
White goods	15%	25%
Brown goods	85%	75%
Most dangerous and hazardous methods to human health		
Open burning	45%	53%
Landfilling	35%	38%
Incineration	20%	9%
Best methods for E&E waste management		
Recycling	70%	75%
Reuse	20%	18%
Disposal	10%	7%

and 18% from India and Switzerland respectively from directories, about 30% and 27% from India and Switzerland respectively from local government advertisements and promotions and about 10% and 3% from India and Switzerland respectively from relatives and friends. From the interview discussions, the interviewees noted that they normally use internet service to get information, which is the most convenient way and can ensure that it is up-to-date. Another interviewee also explained that most information from other sources can also get it from the internet. They will use internet service to find information at the first place.

For recycling different types of E&E equipment, about 15% and 25% of the respondents from India and Switzerland respectively recycle white goods and about 85% and 75% from India and Switzerland respectively recycle brown goods. White goods include household linens and large kitchen appliances such as refrigerators, water heaters, freezers, washing machines, dryers, dishwashers, kitchen compactors, window-unit air conditioners and cookers, which is traditionally white in colour. Brown goods include items that are typically used for audio, video, telecommunications and computing purposes, which contain picture tubes, cathode ray tubes, electronic circuitries or circuit boards. From the interview discussions, the interviewees explained that brown goods items are easily to recycle and to sell. Normally, parts of the equipment are valuable for recycling.

About 45%, 35% and 20% of the respondents from India and about 53%, 38% and 9% from Switzerland, considered that open burning, landfilling and incineration respectively are the most dangerous and hazardous methods to human health. From the interview discussions, an interviewee highlighted that landfilling is the most common method used to solve waste problems in most countries around the world. However, countries with high population to land ratio are tough to use landfilling, in which incineration should be proposed.

About 70%, 20% and 10% of the respondents from India and about 75%, 18% and 7% from Switzerland, are considered recycling, reuse and disposal respectively are the best methods for E&E waste management. From the interview discussions, an interviewee encouraged that partial recycling of E&E waste is the best method to reduce E&E waste. Parts of E&E materials are expensive and easy to recycle; however, sorting and disassemble are required.

CASE STUDY—NEW DELHI, INDIA

Electrical and Electronic Waste Scenario

The E&E industry has emerged as the fastest growing segment of Indian industry in terms of production and exports. Within this segment, the industry is prime mover with an annual growth rate of about 42.4% between 1995 and 2000 (Toxics Link, 2003). By the end of 2000, India had installed about 5 million personal computers. About 1.65 million personal computers were sold in the period of 2001-2002 (Toxics Link, 2003).

The E&E industry has a prominent global presence largely due to a software sector. Promotion of the software industry and protection of a hardware industry from external competition have resulted in this skewed growth. More recently, policy changes have led to a tremendous influx of leading multinational companies into India to set up manufacturing facilities, research and development centres and offshore software development facilities. The domestic market is getting revitalized due to buoyant economic growth and changing consumption patterns.

This growth has significant gained economic and social impacts. The increase of E&E products' consumption rates and high obsolescence rate leads to high generation of E&E waste (Ahluwalia and Nema, 2007). The increasing obsolescence rates of E&E products added to a huge import of junk electronics from abroad create complex scenario for solid waste management in India.

About 50% of personal computers sold in India are products from the secondary market and are re-assembled on old components. The remaining market share is covered by multinational manufacturers (about 30%) and Indian brands (about 22%) (Toxics Link, 2003). Manufacturers are the major contributors of E&E waste. The waste consists of defective integrated circuit chips, motherboards, cathode ray tubes and other peripheral items produced during production processes (Widmer *et al.*, 2005). It also includes defective personal computers under guarantee procured from consumers as replacement items.

Individual households account for about 22% of junk computers in India (Toxics Link, 2003). The preferred practice to get rid of obsolete computers is to get them in exchange from retailers when purchasing a new computer, or passed on to elatives or friends, government, public and private sectors.

The business sector accounts for about 78% of all installed personal computers in India (Toxics Link, 2003). Obsolete computers from the business sector are normally sold by auctions. Sometimes educational institutes or charitable institutions receive old computers for reuse.

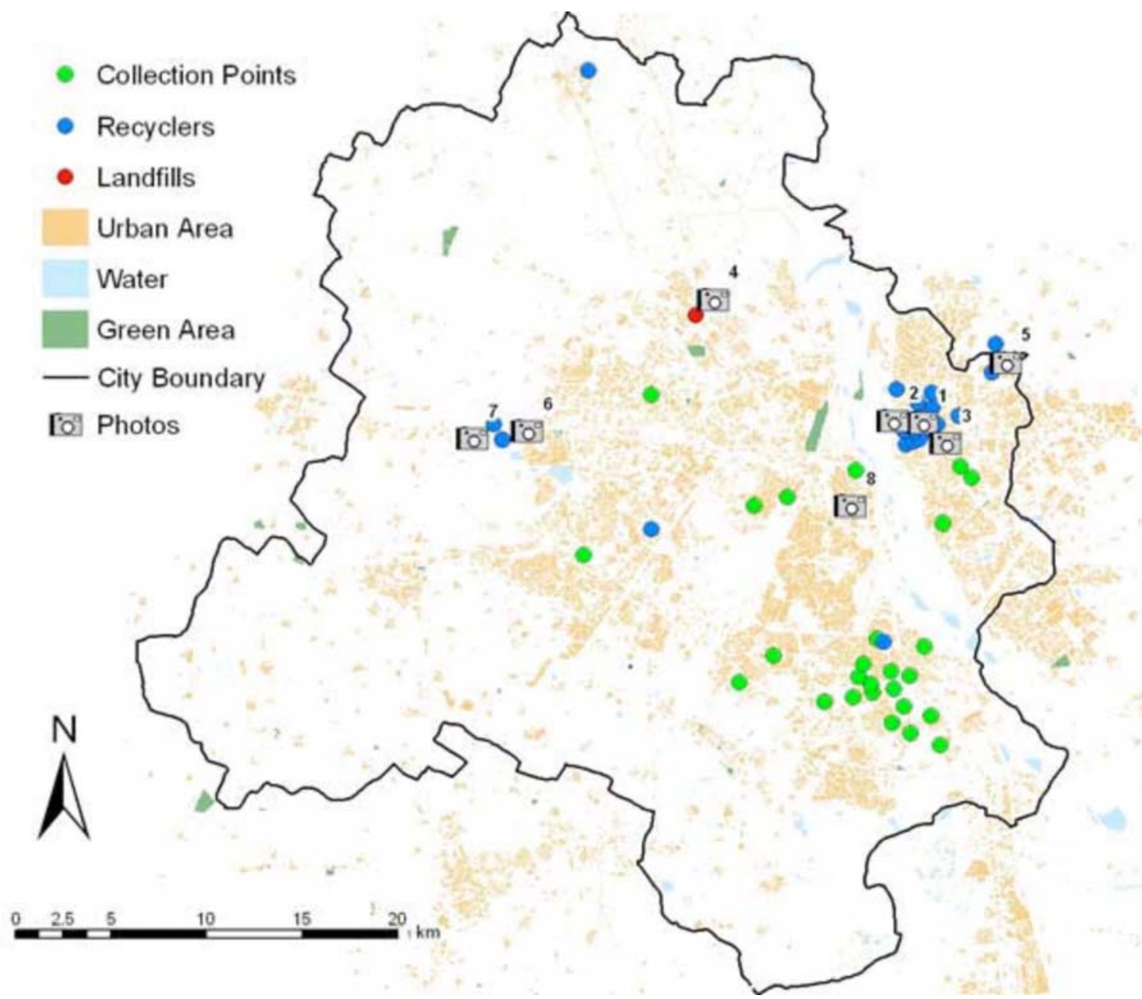
Import of E&E waste is legally prohibited. Nevertheless, there are reports of E&E waste imports from abroad (Toxics Link, 2003). Analyses by the ministry of environment showed no results concerning import of E&E waste, but the ministry admits that a 100% control of the borders is not possible.

A person can work as a trader, scrap dealer and dissembler (Streicher-Porte *et al.*, 2005). Some traders carry out, for example, the primary work of disassembling obsolete computers, and they reuse working components, assemble new computers and sell them again on the secondary market. Non-working components are sold to recyclers.

The market for E&E waste is not concentrated in a single place, but spread over different areas, each handling a different aspect of recycling. No sophisticated machinery or personal protective equipment is used for the extraction of different materials. All work is done by bare hands and only with the help of hammers and screwdrivers. Children and women are routinely involved in the operations. Computer waste, which does not have any resale or reuse values, is openly burnt or disposed off in landfills.

Figure 3 describes locations where different types of processing and recycling can be done in New Delhi, India. It also describes trading and collection units located in the city.

FIGURE 3. Distribution centers in New Delhi, India (Toxics Link, 2003).



Technologies Applied for Electrical and Electronic Waste

Manual Dismantling

The accrued E&E waste in India is manually dismantled and sorted to fractions printed wiring boards, cathode ray tubes, cables, plastics, metals, condensers and others (Streicher-Porte *et al.*, 2005). Nowadays invaluable materials like batteries, television or wood. The valuable fractions are treated in refining and conditioning processes.

Refining and Conditioning

Different E&E waste fractions are directly processed to reusable components and to secondary raw materials in a variety of refining and conditioning processes (Toxics Link, 2003).

Final Disposal

Solid E&E waste is deposited in municipal landfills. Systematic gas and water collecting systems are not installed; hence significant emissions to water and air are caused. Construction sites are crowded with informal waste pickers. People collect valuable materials for recycling.

CASE STUDY—SWITZERLAND

Electrical and Electronic Waste Scenario

E&E waste recycling system has direct and indirect impacts on labour, health and the environment. The recycling system is described through systemic and technological elements. Material and financial flows along the whole product life cycle are qualitatively presented. The recycling system is surrounded by a general framework (Morf *et al.*, 2006). The prevailing economic situation, politics, legislation and its enforcement, science and technology, and cultural aspects influence the interactions within the system. This framework is affected by changes in labour, health and environmental impacts. There is feedback from recycling centre to the framework.

In Switzerland, two take-back systems financed by an advance recycling fee are installed for E&E devices (Hischier *et al.*, 2005). The first system, which covers household equipment including small devices like hair dryers and large devices like electric furnaces and refrigerators, is managed by Stiftung Entsorgung Schweiz. The second system, which covers office electronic and technology equipment, mobile telephones, equipment used in the graphics industry, telephones and telephone switchboard systems, as well as consumer electronics, is operated by Swiss Association for the Information, Communication and Organisational Technologies. The two systems are co-operating on the level of material flow control.

Manufacturers and importers of E&E equipment are responsible for their products up to the end of the products' useful life, and therefore jointly operate a return and recycling system via their association (Morf *et al.*, 2006). The associations need to collect advance recycling fee imposed on new E&E equipment. They further guarantee a smooth recycling operation, paying special attention to the recycling quality and the utilization of funds.

Traders/retailers are an important element in the entire recycling chain, about 58% of all end-used E&E appliances are end up at their stores (Schmidt, 2005). Traders charge an advance recycling fee on each newly sold piece of E&E equipment. This fee stays with the trader who paid the same amount to the importer/manufacturer as part of product's delivery price. As a result, traders/retailers do not make any financial profit out of the recycling system. On the other hand, the recycling scheme provides them with a convenient outlet for E&E waste as retailers and traders are obliged to take back any E&E equipment offered in their assortment by the Swiss ordinance on the return, take-back and disposal of E&E appliances (Hischier *et al.*, 2005). Upon purchase of a new E&E product, consumers have to pay an advance recycling fee. This entitles them to return any old equipment to importers, traders or authorized collection points. Furthermore, the fee on new equipment finances the take back of old equipment bought at a time when the fee had not been implemented yet.

The recycling systems run a number of authorized collection points of about 500 in 2003 in Switzerland (Schmidt, 2005), where any E&E equipment can be returned free of charge. Arrangements for home collections can also be provided. The recycling system operates with about 15 licensed sorting and dismantling companies (Schmidt, 2005), which process E&E waste according to the Swiss Ordinance on the Return, Take-back and Disposal of Electrical and Electronic Appliances. Processing includes manual and mechanical sorting and dismantling, shredding and recovery of materials (Hischier *et al.*, 2005). Depending on their composition, resulting fractions are passed over to refiners, conditioners or final disposers.

Most fractions need to be refined or conditioned, it can then sell as a secondary raw material or dispose in a final disposal site. Refining is performed in refining companies inside and outside Switzerland for fractions like aluminium, batteries, cathode ray tubes, ferrous and non-ferrous metals, recyclable plastics and printed boards (Schmidt, 2005). Conditioning is mainly performed in Switzerland and includes municipal solid waste incineration in of about 36 Swiss plants for fractions such as plastics waste, and hazardous waste incineration for fractions such as condensers (Hischier *et al.*, 2005).

More than 75% (by weight) of material entering the recycling systems is refined to secondary raw materials like aluminium, copper, gold and silver (Morf *et al.*, 2006). About 20% (by weight) of material, mainly plastics, is incinerated (Morf *et al.*, 2006). About 3% (by weight) of material entering the recycling system ends up in landfills (Morf *et al.*, 2006). Swiss landfills are subject to a relatively strict emission control and are comparatively restrictive regarding the materials accepted since the year 2000 combustive materials have no longer been admitted for final disposal in landfills.

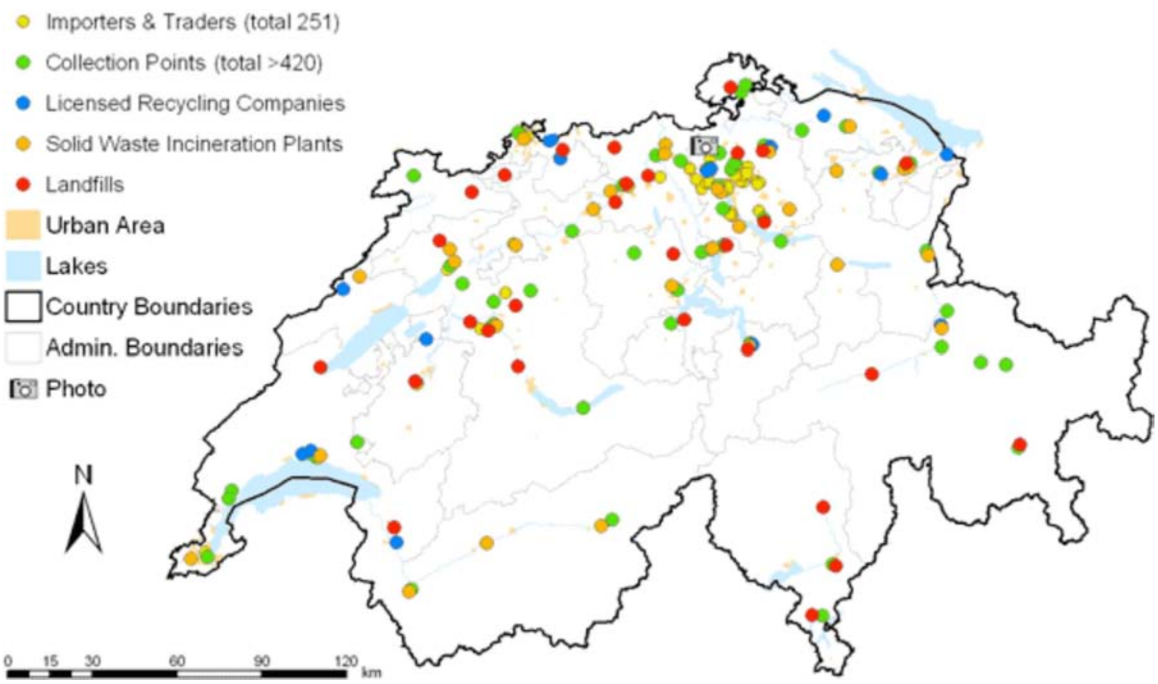
Figure 4 describes locations where different types of processing and recycling can be done in Switzerland. There are about 251 importing and trading centres located in the city, which is supported by about 430 collection points (Schmidt, 2005). The licensed recycling plants and solid waste incineration plants are evenly distributed. There are several landfills, located in the city, which plays a very important role in the recycling.

Technologies Applied for Electrical and Electronic Waste

Manual Dismantling

Manual dismantling is a first and traditional way to separate hazardous materials from recyclable materials. In a pre-sorting process, the incoming E&E waste is separated into different categories, which are to be separately handled in dismantling and sorting processes (Morf *et al.*, 2006). The dismantling process is performed with simple tools such as screwdrivers, hammers and tongs.

FIGURE 4. Distribution centers in Switzerland (Schmidt, 2005).



Mechanical Disassembly

Mechanical disassembly is the second and modern way to separate hazardous materials from E&E waste. In a pre-sorting process, the incoming E&E waste is separated into different categories, which are to be separately handled in dismantling and sorting processes. The dismantling process itself is performed mechanically. Typical components of a mechanical dismantling plant are crushing units, shredders, magnetic separators and air separators (Cui and Forssberg, 2003). The exhaust gases are cleaned up in waste gas purification plants and dust generated collected with dust filters. Indoor exposure to be monitored and assessed relative to the Swiss maximum allowable concentration values.

Refining and Conditioned

Most fractions need to be refined or conditioned, it can then sell as secondary raw materials or to dispose in a final disposal site. Refining includes mechanical, thermal and chemical processes (Morf *et al.*, 2006). It is typically performed for fractions such as batteries, cathode ray tubes, ferrous and non-ferrous metals, recyclable plastics and printed boards. Many refining processes take place outside Switzerland, entailing greater transport distances. Conditioning includes municipal solid waste incineration of fractions such as plastics waste in one of 36 Swiss plants and hazardous waste incineration of fractions such as condensers in one of 7 Swiss plants (Morf *et al.*, 2006).

Final Disposal

Final disposal of materials from dismantling, refining and conditioning processes takes place in landfills (Tam and Tam, 2006). Swiss landfills are subject to relatively strict emission controls and are comparatively restrictive regarding materials accepted, since the year 2000 combustive materials have no longer been admitted for final disposal in landfills (Schmidt, 2005).

COMPARISONS BETWEEN TWO CASE STUDIES

E&E waste recycling is implementing around the world as large quantities of E&E equipment are coming into the waste stream. Effectively and efficiently managing the increasing volumes of E&E waste is a complex task. Firstly, special logistic requirements are necessary for collecting E&E waste. Secondly, E&E waste contains many hazardous substances which are extremely dangerous to human health and the environment; disposal requires special treatment to prevent the leakage and dissipation of toxics into the environment. At the same time, if it is a rich source of metals such as gold, silver and copper, it should be recovered and brought back into the production cycle. This particular characteristic of E&E waste has made waste recycling as a lucrative business in both developed as well as developing countries. While some countries have organised systems for the collection, recycling, disposal and monitoring, other countries are still finding a solution that ensures jobs while minimizing the negative environmental impacts of E&E waste recycling.

Two case studies from India and Switzerland were selected. Switzerland was chosen because it was the first country to implement an industry-wide organised system for the collection and recycling E&E waste. Having been operation for a decade, the Swiss system provides the best opportunity to study the evolution of an E&E waste management system. India was chosen as the other country for study because it is one of the fastest growing markets for the consumption of E&E appliances, and it has a large recycling industry, which has emerged as a major market for old and junked computers.

In the following discussions, it is compared four areas between India and Switzerland: i) E&E intensity per service unit; ii) employment potentials; iii) occupational hazards; and iv) emissions of toxics .

Electrical and Electronic Intensity Per Service Unit

A high value in E&E intensity per service unit leads to a high annual accrual of E&E waste per capita. E&E intensity per service unit is inversely proportional to the average product service life. Compared to India, Switzerland shows a higher value in E&E intensity per service unit with its more widespread use of appliances and shorter product service lives, given a lower rate of repair and reuse. In 2003, more than 9kg of E&E waste per resident were taken back in Switzerland by the recycling systems (Schmidt, 2005).

Employment Potentials

Using the employment potentials offered by the system, it can be seen that the Indian E&E waste recycling system generates more jobs than the Swiss system, in term of per tonne of E&E waste processed. Collection, dismantling, sorting and segregation and even metal recovery are done manually in India. Therefore, the E&E waste recycling sector, albeit informal, employs many unskilled or semi-skilled workers. While there are no national figures yet available, estimates of the study show that at least 10,000 people are involved in the recycling and recovery operations in New Delhi, India (Toxics Link, 2003). The figure would be much higher if the entire value chain of collectors, transporters and traders, is included. Comparatively, E&E waste management in Switzerland is highly mechanized, and employs fewer people. For example, the recycling system, which manages discarded household appliances totalling over 34,000 tonnes, engages 470 people including collection, transportation, recycling, administration and controlling (Streicher-Porte *et al.*, 2005). The main reason for this large difference in the number of people employed is the availability of cheap manpower in India as compared to the high labour costs in Switzerland. An E&E waste recycler in India earns approximately US$3.48 per day, as compared to US$127.35 in Switzerland (Morf *et al.*, 2006; Schmidt, 2005; Streicher-Porte *et al.*, 2005).

Occupational Hazards

In considering the perspective of occupational hazards, E&E waste handlers in India are at a higher risk than in Switzerland. Major reasons are the low level of awareness among workers regarding chemical hazards and processes and the lack of formal guidelines as well as a lax enforcement of the existing environmental laws.

Urban Environmental Quality

Urban environmental quality is directly affected by the locations of E&E waste collection points, recycling facilities, landfills and incineration plants as it can pollute the environment if it is too close to the residential areas or urban areas. Figure 3 and Figure 4 show the locations of the distribution centers in India and Switzerland respectively. In India, there is only one landfill, a few recycling facilities, and a lot of E&E waste collection points; however, all are located in the urban areas. In Switzerland, there are a lot of landfills, incineration plants, a few recycling facilities and reasonable amount of E&E waste collection points, and they are mainly located in the rural areas. From that, it can clearly highlight that the urban environmental quality in India is relatively lower than that in Switzerland.

Emissions of Toxics

Due to the manual processes used for materials recovery, the level of toxics such as dioxins and acids released has been found to be higher in India than in Switzerland. Culpable for the high levels of these externalities are backyard processing techniques such as open burning of cables, which is conducted in an open space without any controls or precautions. The material flow in and out of the system is totally unmonitored at present. In contrast, the Swiss system imposes high safety and emission standards and mphasizes the implementation of regular controls and monitoring at every stage of the material and financial flow through the system. External auditors carry out at least one annual audit at each recycler, and unless standards are complied with, the recycler's licence is revoked. This monitoring has the effect that E&E waste recyclers stay within the strict Swiss emission limits.

Table 2 summarizes the comparison between the two case studies.

TABLE 2. Comparison between two case studies.

Criterion	India	Switzerland
E&E intensity per service unit	Low, positive	High, negative
Employment potentials	High, positive	Low, negative
Occupational hazards	High, negative	Low, positive
Urban environmental quality	Low, negative	High, positive
Emissions of toxics	High, negative	Low, positive

RECOMMENDATIONS FOR EFFECTIVE E&E WASTE MANAGEMENT AND ITS IMPLICATIONS TO GREEN BUILDING

From the survey results and interview discussions, the following methods are suggested to improve E&E waste recycling:

- It should be encouraged by policies and incentives: (i) to take back products' packaging; (ii) to reduce volumes and toxicity of waste for maximum reuse, recycling and/or composting; (iii) to buy reusable, recycled and durable materials and products; and (iv) to eliminate waste and packaging by redesigning manufacturing processes.
- Repair shops for E&E equipment should be provided at convenient locations in the city. This can enhance people to repair their E&E equipment, instead of degrading it.
- Material exchange for E&E equipment is suggested. This can help reusing old E&E equipments to other organizations such as charities, by purchasing new equipments. Dealers will sell the new E&E equipment and receive the old equipment, which will then send the old equipment for proper recycling.
- Buyback recycling centers should be placed at several places to receive used bottle, metal and paper products.

An effective E&E waste management can help improve the implementation to green building. Some E&E products can easily be reused or recycled. When the industry designs or constructs green building, they can consider using and including reused or recycled E&E products or some longer life-cycle E&E products as their equipment or facilities for the end users. The initial cost for these products may be higher; however, the life cycle cost will be able to reduce as maintenance cost and life span for the products are better. This can significantly help the implementation in green building and provide a link for E&E waste management and green building.

CONCLUSION

This paper investigated electrical and electronic (E&E) waste recycling in the Indian and Swiss industry. Questionnaire surveys, structured interviews and case studies were conducted. Four major areas were compared between India and Switzerland: i) E&E intensity per service unit; ii) employment potentials; iii) occupational hazards; and iv) emissions of toxics. It was found that India performs better in E&E intensity per service unit and employment potentials, while Switzerland performs better in occupational hazards and emissions of toxics. Recommendations to improve the existing E&E waste recycling situations and its implications to green building were also given.

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