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Waste electrical and electronic equipment (WEEE) management in Korea: generation, collection, and recycling systems

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Abstract In Korea, generation of waste electrical and electronic equipment (WEEE), or electronic waste (e-waste), has rapidly increased in recent years. The management of WEEE has become a major issue of concern for solid waste communities due to the volumes of waste being generated and the potential environmental impacts associated with the toxic chemicals found in most electronic devices. Special attention must be paid when dealing with WEEE because of toxic materials that it contains (e.g., heavy metals, polybrominated diphenyl ethers, phthalates, and polyvinyl chloride). If managed improperly, the disposal of WEEE can adversely affect the environment and human health. Environmental regulatory agencies; electronic equipment manufacturers, retailers, and recyclers; environmental non-governmental organizations; and many others are much interested in updated statistics with regard to how much WEEE is generated, stored, recycled, and disposed of. In Korea, an extended producer responsibility policy was introduced in 2003 not only to reduce the amount of electronic products requiring disposal, but also to promote resource recovery from WEEE; the policy currently applies to a total of ten electrical and electronic product categories. This article presents an overview of the current recycling practices and management of electrical and electronic waste in Korea. Specifically, the generation rates, recycling systems and processes, and recent regulations of WEEE are discussed. We estimated that 1263000 refrigerators, 701000 washing machines, 1181000 televisions, and 109000 air-conditioning units were retired and handled by the WEEE management system in 2006. More than 40% of the products were collected and recycled by producers. Four major producers' recycling centers and other WEEE recycling facilities are currently in operation, and these process a large fraction of WEEE for the recovery of valuable materials. Much attention should still be paid to pollution preven-

tion and resource conservation with respect to WEEE. Several suggestions are made in order to deal with electronic waste management problems effectively and to prevent potential impacts.

Key words WEEE · Electronic waste · e-waste · Recycling system · EPR

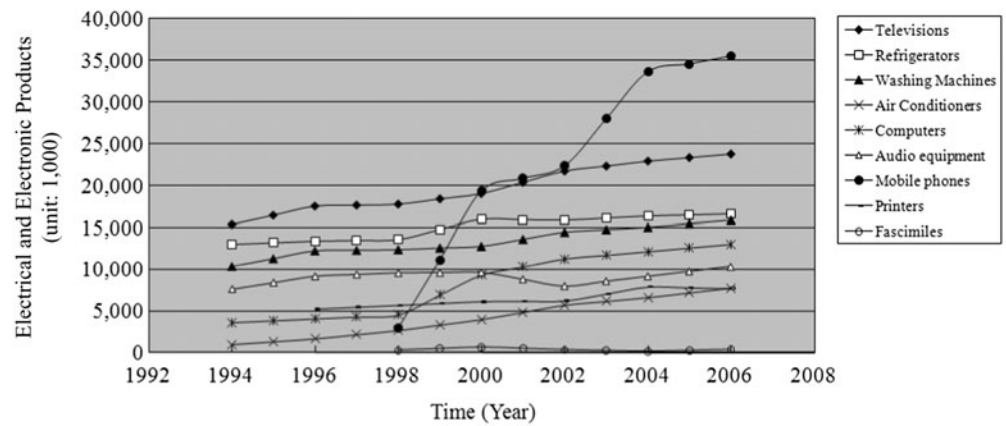
Introduction

The republic of Korea, with a population of over 48 million people, has a high environmental pollution loading due to its rapid industrial development and high population density. The rapid growth of Korean electronics manufacturers (e.g., Samsung, LG, and Daewoo) and the information technology industry in Korea has become the major driving force for the expansion of domestic markets for electronic products. The production and sale of home appliances and electronic devices have rapidly increased over the past two decades. Recent statistics show that as of 2006, more than 35 million mobile phones, 22 million televisions, and about 13 million personal computers were in use in Korea, as shown in Fig. 1.¹ More than 75% of the total population use the Internet.² As liquid-crystal-display (LCD) and plasma-display-panel (PDP) televisions replaced cathode-ray-tube (CRT) televisions, domestic demand for all televisions in 2006 increased to about 2.4 million in Korea.¹ As of 2008, there were more than 45 million mobile phone subscribers, and approximately 19 million mobile phones were sold in Korea in 2007.^{1,3}

When electrical and electronic products reach the end of their useful life, they become waste electrical and electronic equipment (WEEE), which is often referred to as electronic waste (or e-waste for short). Waste electrical and electronic streams encompass a wide range of electrical and electronic waste products, including home appliances (e.g., refrigerators, washing machines, and air conditioners); information technology and telecommunication equipment (e.g., personal computers, laptop computers, printers, copying equipment, calculators, facsimiles, telephones, and

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Fig 1. Number of electrical and electronic products in use in households in Korea



mobile phones); consumer electronic devices (e.g., televisions, radios, video cameras, and audio equipment); and other household electrical and electronic equipment (e.g., vacuum cleaners, toasters, coffee machines, hair dryers, watches, and irons). The categories and scope of WEEE may vary depending on the definition and regulations of the waste stream in a given country. The detailed definition and categories of WEEE are discussed in a later section. In this article, the terms “WEEE” and “e-waste” are synonymously and interchangeably used, although WEEE is a more broad definition and refers to all electrical and electronic wastes generated by consumers, including home appliances, information technology and telecommunication equipment, and consumer electronic devices. E-waste is often considered to be a subcategory of WEEE and indicates “electronic” products that are discarded by consumers.

Electrical and electronic waste represents one of the fastest growing solid waste streams in Korea. In many parts of the world, the large consumer demand for newer electronic products and the advanced development of information and communication technology (ICT) have resulted in tremendous amounts of WEEE that are disposed of. The disposition and management of WEEE is an emerging environmental issue of concern for the solid waste communities in Korea and around the world. The lifespan of electronic devices is becoming shorter, and so the quantity of WEEE is expected to increase. For example, the lifespan of personal computers has decreased from 4–6 years to often less than 2 years at present. In 2004, more than 180 million personal computers were sold worldwide, while 100 million computers were estimated to be obsolete, with some recycled to recover materials.⁴ A recent study reported that approximately 130 million mobile phones were retired in the United States in 2005, with a cumulative estimate of more than 700 million phones already discarded or stockpiled prior to disposal.⁵ In Canada, approximately 23500 tons of information technology equipment, such as personal computers, notebook computers and peripherals, were disposed of in 2005.⁶ Sales of notebook computers have substantially increased over the past decade, and so the number of notebook computers discarded will increase in the waste stream.

In addition to the difficulties caused by the vast amount of WEEE produced, there is a risk posed by the myriad of toxic chemicals present in WEEE, including metals (e.g., arsenic, cadmium, chromium, copper, lead, and mercury) and organic chemicals (e.g., polybrominated diphenyl ethers as flame retardants, phthalates, and polyvinyl chloride). Thus, concerns have been raised that toxic chemicals could leach from these wastes when improperly disposed of or handled.^{7–13} The composition and amount of toxic chemicals found in WEEE largely depend on factors such as the type of electronic device and the model, manufacturer, and date of manufacture. For example, printed circuit boards found in most electronic devices may contain arsenic, cadmium, chromium, lead, mercury, and other toxic chemicals. Typical printed circuit boards treated with lead solder in obsolete electronic devices have been reported to contain approximately 50 g of tin–lead solder per square meter of circuit board.¹⁴ Cathode ray tubes in computer monitors and televisions may contain barium, cadmium, copper, lead, zinc, and other rare earth metals. In cathode ray tubes, leaded glass provides shielding from X-rays generated during the picture projection process. A color cathode ray tube typically contains 1.6–3.2 kg of lead on average.¹⁵ With a growing concern regarding the leaching of lead and other metals, several states in the US recently banned cathode ray tubes from landfills because of their toxic characteristics.^{16,17}

The toxic chemicals from many electronic devices can be released into the environment and could pose a significant threat to human health via recycling and uncontrolled treatment processes.^{8,13,18} The disposal of WEEE with the rest of the municipal solid waste (MSW) stream in a landfill may result in negative impacts on the environment (e.g., groundwater contamination by lead leaching and high concentrations of lead in landfill leachate). When WEEE is burnt in incinerators, heavy metals become concentrated in the ash, limiting its disposal and reuse options. Since most of the plastic materials in WEEE contain flame retardants that are mainly halogenated organic chemicals, toxic organic contaminants such as dioxins and furans may be formed during incineration and exit through the stack to the surrounding area in the form of gaseous pollutants. Thus far, limited

knowledge exists regarding the extent to which management of WEEE via traditional waste management systems, such as landfilling and incineration, has caused adverse impacts on the environment.^{19–22}

In response to growing concern, many parts of the world are trying to seek environmentally sound and economically feasible models for WEEE management. Many countries have shown great interest in establishing recycling processes to reduce the quantity of WEEE to be disposed of and to recover valuable resources. Unlike that for municipal solid waste, the WEEE management system is not well established in most countries. A number of studies have been recently published to provide current knowledge and/or to address potential problems associated with WEEE management.^{10,23–29}

This article presents an overview of the current recycling practices and management of WEEE in Korea. The generation rates of WEEE in Korea have been estimated. Also discussed are the historical and recent regulatory efforts regarding WEEE recycling with an emphasis on the extended producer responsibility (EPR) policy, which was introduced in 2003 in Korea. The current collection system, material flow, and recycling rates of WEEE are presented, followed by the processes at existing electronic waste recycling facilities. Finally, suggestions are made for establishing environmentally sound recycling and management systems of WEEE in Korea.

Methodology

The methodology of this study included gathering data associated with annual domestic demands (or sales) of selected home appliances and electronic devices, site visits, questionnaire surveys, interviews and conversations, and a review of the available literature. The devices covered in this article are mainly televisions, refrigerators, washing machines, air conditioners, personal computers, audio equipment, mobile phones, printers, copying machines, and facsimiles. The annual domestic demands of the products were obtained from the Bureau of Statistics in Korea. Statistical data regarding the amount of retired WEEE were obtained by using surveys, previous research reports, statistical data from the governmental sector, and scientific articles.^{1,3,29–32} Site visits to local electronics retailers, private reuse market dealers, WEEE recycling centers and facilities, and the Korea Association of Electronics and Environment (Korea AEE) were carried out to support and supplement information gathered by the surveys. The Korea AEE, a producer responsibility organization (PRO), was established in 2000 as a cooperative effort to share the responsibility of environmentally sound WEEE recycling between the electronic industry and its members. WEEE recycling processes were examined during the facility visits. The results of the questionnaire surveys regarding the patterns and rates of consumption and disposal of electronic devices by consumers, retailers, and local governments were used to estimate the generation rate of the selected WEEE categories. Interviews and conversations with environmental regulatory

agencies, recycling industry experts, and PRO committees were conducted to obtain details of recent progress and development associated with WEEE management. The available literature was reviewed to allow comparisons to be made with the collection and recycling of WEEE in other countries and regions.

Definition and generation of WEEE in Korea

Definition and scope of electrical and electronic equipment

Since numerous electrical and electronic devices are being used in our modern society, it is important for the solid waste community to recognize how to define and classify the devices according to the laws and regulations as part of waste management practices. There is no widely accepted definition of discarded electrical and electronic devices around the world. In most cases, electronic waste (or e-waste) is used as a generic term to describe obsolete or end-of-life (EOL) electronic devices and comprises the relatively expensive and durable products used for information processing, telecommunications, or entertainment in households and businesses.²⁸ E-waste refers to all electronic devices used by consumers that are discarded and not intended for further use. It generally consists of many different types of electronic devices such as televisions, personal computers and monitors, laptop computers, mice, keyboards, printers, scanners, copy machines, facsimiles, telephones, mobile phones, audio equipment, and video cameras. In recent years, high-definition liquid-crystal-display televisions, mobile phones, computers, portable digital assistants, and MP3 players have experienced rapidly increasing sales and are replaced frequently.

WEEE is another term that is often used interchangeably with e-waste, but includes a greater variety of home appliances and electrical equipment (e.g., refrigerators, washing machines, air conditioners, vacuum cleaners, toasters, coffee machines, hair dryers, watches, and irons). In Europe and in many other regions and countries, WEEE is a commonly used regulatory and technical term and includes electrical and electronic items that are widely used in the home. According to the European Union (EU) WEEE directive, WEEE is specifically defined as electrical and electronic equipment which consumers dispose of or are required to dispose of pursuant to the provisions of national law, including all components, subassemblies, and consumables.³³ In the EU directive, WEEE consists of ten categories and covers a total of 96 device types or pieces of equipment, including large and small home appliances, information technology and telecommunications equipment, lighting equipment, medical devices, automatic dispensers, and others categories.³³ In Japan, the Law for Recycling Home Appliances was enacted in June 1998 to establish a recycling framework that places the obligation for handling waste items on the manufacturers and retailers of home appliances. A recent study discussed the Japanese system for recycling waste home electrical appliances.³⁴

Table 1. Definition and scope of waste electrical and electronic equipment (WEEE) or electronic waste^{27,28,33–35}

Country	Term	Scope	Types of device or equipment
EU	WEEE “Electrical or electronic equipment (EEE) which is waste, including all components, subassemblies and consumables that are part of the product at the time of discarding.”	Large home appliances	Refrigerators, washing machines, dish washing machines, microwaves, electric heaters, air conditioners
		Small home appliances	Vacuum cleaners, toasters, coffee machines, hair dryers, watches, irons, and other appliances
		IT and telecommunications equipment	Personal computers, laptop computers, printers, copying equipment, calculators, facsimiles, telephones, mobile phones
		Consumer equipment	Radios, televisions, video cameras, audio amplifiers,
		Lighting equipment	Fluorescent lamps, high-density discharge lamps
		Electrical and electronic tools	Drills, saws, sewing machines, tools for screwing, welding equipment, mowers and gardening equipment
		Toys, leisure and sports equipment	Video games and consoles, electric trains and car racing sets
		Medical devices	Radiotherapy equipment, dialysis, pulmonary ventilators
		Monitoring and control instruments	Smoke detectors, thermostats, heating regulators
Korea	WEEE	Limited electrical equipment and electronic devices	Automatic dispensers for hot drinks, solid products, bottles or cans, automatic dispensers for money
Japan	WEEE	Home appliances	Refrigerators, washing machines, air conditioners, televisions
China	WEEE, same definition as the EU Directive	Limited electrical equipment and electronic devices	Refrigerators, washing machines, air conditioners, personal computers, televisions
US	Electronic waste (or e-waste)	Electronic products that are discarded by consumers	Televisions, computer monitors, computers and computer peripherals, audio and stereo equipment, VCRs and DVD players, video cameras, telephones, mobile phones, fax and copy machines, video game consoles

Table 1 presents the definitions and scope of WEEE or electronic waste.^{27,28,33–35} Although a clear distinction between e-waste and WEEE may be difficult to achieve, it is important to understand that one should be cautious of using the exact definition and category of the terms e-waste and WEEE.

In Korea, WEEE is the more commonly used and preferred term, and it was recently defined as “any electrical or electronic devices that are no longer in use and have been discarded by consumers” by the Act on Resource Recycling of Waste Electrical Electronic Equipment (WEEE) and End-of-life Vehicles (ELVs).³⁵ The Act was enacted in April 2007; it will be further discussed in a later section. Unlike the classification of WEEE in the EU, the category and type of WEEE in Korea is currently very limited and includes a total of ten types of electrical and electronic devices (i.e., refrigerators, washing machines, televisions, air conditioners, computers, printers, facsimiles, audio equipment, copy machines, and mobile phones), as shown in Table 1. As regulations strengthen, this list may be expanded and updated in the future. This study primarily discusses the generation and management of such devices in Korea.

Other common terms associated with WEEE may include “end-of-life (EOL) electronics” and “discarded consumer electronic devices (CEDs).” The terms “white goods” (e.g., washing machines, refrigerators, and ovens) and “brown goods” (e.g., Televisions, computers, and radios)

have also been used for dealing with specific categories in electronic and electrical waste streams.

Generation of WEEE in Korea

In order to develop proper WEEE management strategies, it is important to characterize the quantities and composition of WEEE. The quantities and composition can be influenced by several factors, including economic conditions, availability of a reuse market, infrastructure of the recycling industry, waste segregation programs, and regulation enforcement. Unlike municipal solid waste, only limited studies have been carried out to estimate the generation of WEEE in Korea.^{29–32} It should be noted that the estimated number of retired WEEE items should not be equated with the amount of generated WEEE. In this article, the word “retired” refers to WEEE that has reached the end of its useful life. The retired number represents what is theoretically available for waste collection and recycling. Some fraction of these products that have been retired is resold or loaned to others, or is stored at households and is destined to enter the WEEE stream at a later date. When WEEE is collected, reused, recycled, treated, and disposed of, it is referred to as having been “generated.”

The estimation method of the amount of WEEE generation is usually based on domestic demand for electrical and

Table 2. Generation of selected WEEE categories (in thousands of units) in Korea^{1,29,30}

Year		Refrigerators	Washing machines	TVs	Air conditioners	Total
2004	Amount of device in use	23851	15068	22910	6615	68444
	WEEE retired from businesses and households	1336	814	1581	152	3883
	WEEE retired from households	1122	700	1281	102	3205
	WEEE stored/loaned	220	76	336	18	650
	Estimated waste generation	902	624	945	84	2555
2005	Amount of device in use	25406	15500	23350	7210	71466
	WEEE retired from businesses and households	1423	837	1611	165	4036
	WEEE retired from households	1195	720	1305	110	3330
	WEEE stored/loaned	234	78	342	19	673
	Estimated waste generation	961	642	963	91	2657
2006	Amount of device in use	26849	15905	23758	7752	74264
	WEEE retired from businesses and households	1515	859	1639	178	4191
	WEEE retired from households	1263	701	1181	109	3254
	WEEE stored/loaned	250	81	348	21	700
	Estimated waste generation	1013	625	873	89	2600

electronic products and their average lifespan (i.e., the length of the time between the initial purchase of an electronic device and the time it completes its useful life). Lifespans of devices vary depending upon the type of device, economic and market conditions, customer age group (or generation), and cultural behavior. It was estimated in 2006 that the average lifespans were 7.7 years for refrigerators, 7.6 years for washing machines, 7.3 years for televisions, and 6.0 years for air conditioners.³⁰ Shorter lifespans of 4.0 years were found for computers, 4.3 years for printers, and 2.4 years for mobile phones.^{30,32} By combining the sales data and applying lifespan assumptions for each product, the annual units (or sometimes the corresponding weight) of a product that is retired and undergoes waste management via reuse and refurbishment, recycling, export, or disposal are predicted (i.e., the amount of WEEE retired). The estimated amount of WEEE generated was determined from the retired amount of WEEE by subtracting the volume of WEEE that is reused, loaned, or stored at households. The proportions of items reused, loaned, or stored in the household have been estimated using a consumer survey.³⁰

The estimated numbers of selected electronic appliance categories that were retired and the waste generated between 2004 and 2006 are shown in Table 2. During these years, the quantity of selected WEEE generated each year was approximately 2.6 million units (Table 2). Refrigerators were the largest contributor and accounted for nearly 40% of the selected WEEE items, followed by televisions and washing machines. As shown in Table 2, more than 74 million units of televisions, refrigerators, washing machines, and air conditioners were in use in households in 2006. During the same year, the total number of these four products retired was approximately 4.2 million units. By considering the common usage patterns of many other home appliances, the annual number of the products to be retired and generated is projected to continually increase due to increasing sales and decreased lifespans of the devices. Details on the data resources, assumptions, and calculations underlying the generation estimates can be found elsewhere.³¹

Assuming a standard weight for each product type (31 kg for televisions, 67 kg for refrigerators, 48 kg for washing

machines, and 67 kg for air conditioners), then 131 000 tons of the selected WEEE categories was generated in 2006, representing approximately 0.72% of the municipal solid waste stream in Korea (calculated on the basis of 18 million tons of municipal solid waste generation in 2006). This corresponds to approximately 2.7 kg of selected WEEE/capita/year (based on an assumed Korean population of 48 million).

In Japan, more than 22 million televisions, refrigerators, washing machines, and air conditioners were estimated to be have been generated as waste in 2005.³⁶ Approximately 7.5 million used computers were generated in Japan in 2004.³⁷ In China, a recent study showed that in 2005, the estimated numbers of obsolete refrigerators, washing machines, televisions, air conditioners, and computers were 9.8, 7.6, 33.5, 0.65, and 4.5 million units, respectively. The total mass of obsolete units of these five selected WEEE categories was estimated to be about 1.76 million tons in China in 2003. In 2010, the annual number of these units retired is estimated to be 105 million.^{24,27} In the US, it was estimated that between 1980 and 2004 as many as 180 million units of televisions, computers, computer peripherals, and cell phones were still in storage awaiting disposal. Among these, televisions and computers accounted for 34% and 52%, respectively.³⁸ Another study estimated that over 315 million computers would reach the end-of-life stage in the US by 2003.³⁹ An industry research report showed that approximately 270 million electronic items (computers, televisions, VCRs, mobile phones, and monitors) were removed from US households in 2005.⁴⁰ According to the US EPA, approximately 1.4–1.7 million tons of the devices were primarily disposed of in landfills, and only 0.31–0.34 million tons were recycled in 2005 in the US.³⁸

Regulatory responses to WEEE in Korea: extended producer responsibility (EPR) and the laws relating to WEEE

In response to the increasing volumes of WEEE and their potential environmental impacts through various disposal pathways, several measures and regulations have been developed to properly manage such waste in Korea. Korea's

Table 3. Target recycling rates and the amount of WEEE handled (in tonnes) by the extended producer responsibility (EPR) system in Korea⁴³

Type of WEEE	2006			2007			2008		
	Domestic demand	EPR target rate	Amount recycled by producers	Domestic demand	EPR target rate	Amount recycled by producers	Domestic demand	EPR target rate	Amount recycled by producers
Refrigerators	91007	11467	14568	85956	11432	18957	95107	13790	18657
Washing machines	260950	44101	44645	261575	45252	50832	230796	43620	53535
Televisions	94899	22206	22200	98794	23908	23908	79759	20179	22034
Air conditioners	135882	2310	2211	130303	2475	2906	116105	2438	2431
Computers	43193	4060	4934	46399	4547	6061	83186	8567	9906
Audio	2410	306	377	1979	259	403	5985	891	1169
Mobile phones	2928	451	451	2836	468	468	3146	566	710
Copying machines	5748	483	1293	4130	388	493	3838	487	497
Facsimiles	1250	105	110	1012	95	171	720	82	110
Printers	21065	1769	1771	12290	1130	1551	10996	1231	1231

first law to regulate WEEE, the Act on the Promotion of Conservation and Recycling of Resources (also called the Waste Recycling Act), took effect in 1992. Two home appliance categories, televisions and washing machines, were first regulated by the Act, and air conditioners and refrigerators were included in 1993 and 1997. The Korea Ministry of Environment (Korea MOE) introduced the Waste Deposit-Refund System for limited categories of home appliances, packaging materials (e.g., glass, plastics, and cans), and other items (e.g., lubricating oil, batteries, tires, and fluorescent lamps) as part of the Act in 1992.⁴¹ The “recycling fee” was deposited by manufacturers (or producers) and importers based on the annual production of their products in the deposit-refund system. When they collected and recycled their obsolete products, the deposited money was refunded to them in proportion to the product numbers they recycled. Money that was not refunded was contributed to the collection and recycling system for the waste materials. The objectives of the system were to reduce the environmental burden caused by the disposal of recyclable products and to encourage producers to recycle their products that have reached the end-of-life stage. However, it was not successful in encouraging collecting and recycling of waste materials because of low economic incentives to the producers. For some of the products, manufacturers often had to pay more to recycle their waste materials than the money they deposited.

In 2003, the MOE modified the Waste Recycling Act to promote effective collection and recycling of waste materials and promulgated an extended producer responsibility (EPR) regulation for the items covered by the Waste Deposit-Refund System and for personal computers and monitors.⁴² EPR involves producers taking more responsibility for managing the environmental impacts of their products throughout their lifecycle. Producers that manufacture the EPR products must collect and recycle an assigned quantity based on a certain percentage of their annual production volume. If this is not achieved, they must pay more than the cost of recycling the waste products. Mobile phones and audio equipment were included in the EPR list in 2005, while printers, facsimiles, and copying machines were included in 2006.

In 2007, new legislation, the Act on the Resource Recycling of Waste Electrical Electronic Equipment (WEEE) and End-of-life Vehicles, was enacted.³⁵ The Act is aimed at reducing the amount of WEEE going to landfills and incinerators, achieving a high recycling rate for all targeted products by adopting the EPR policy, and improving the overall environmental performance of electronic products during their lifecycle. This new legislation is the counterpart of EU directives such as the WEEE directive,³³ the restriction of use of certain hazardous substances (RoHS) directive,⁴³ and end-of-life vehicle (ELV) directive.⁴⁴ This underlines the overall ambition of the Korea MOE to minimize all possible environmental impacts caused by WEEE disposal. It should be thought of as a major response to growing concerns about the WEEE management issue in Korea. Producers, importers, distributors, consumers, and all other parties should be involved in the collection, treatment, recovery, and environmentally sound disposal of WEEE. Producers are required to finance the collection, recycling, and disposal system of WEEE.

Table 3 presents the target and actual recycling rates of WEEE under the EPR policy in Korea between 2006 and 2008.⁴⁵ The annual mandatory recycling rate of each product is determined by the Korea MOE, based on the target recycling rates over the previous 2 years, the amount of electrical and electronic products shipped from the warehouse, and the recycling market conditions. The total amount of the EPR mandatory recycling is determined by the annual amount of electrical and electronic products shipped from the warehouse multiplied by the annual mandatory recycling rate. In 2008, the weights of items to be recycled under the EPR scheme as determined by the Korea MOE were 43620 tons for refrigerators, 20179 tons for televisions, 13790 tons for refrigerators, and 2438 tons for air conditioners. The amounts of all the EPR products recycled by producers with the exception of air conditioners exceeded their mandatory target rates. This indicates that the recycling of WEEE has been successfully performed as a result of the implementation of the EPR system.

In order to effectively achieve the recycling rates of WEEE imposed by the Act, hazardous substances should be absent or minimally present in the products. The Act also

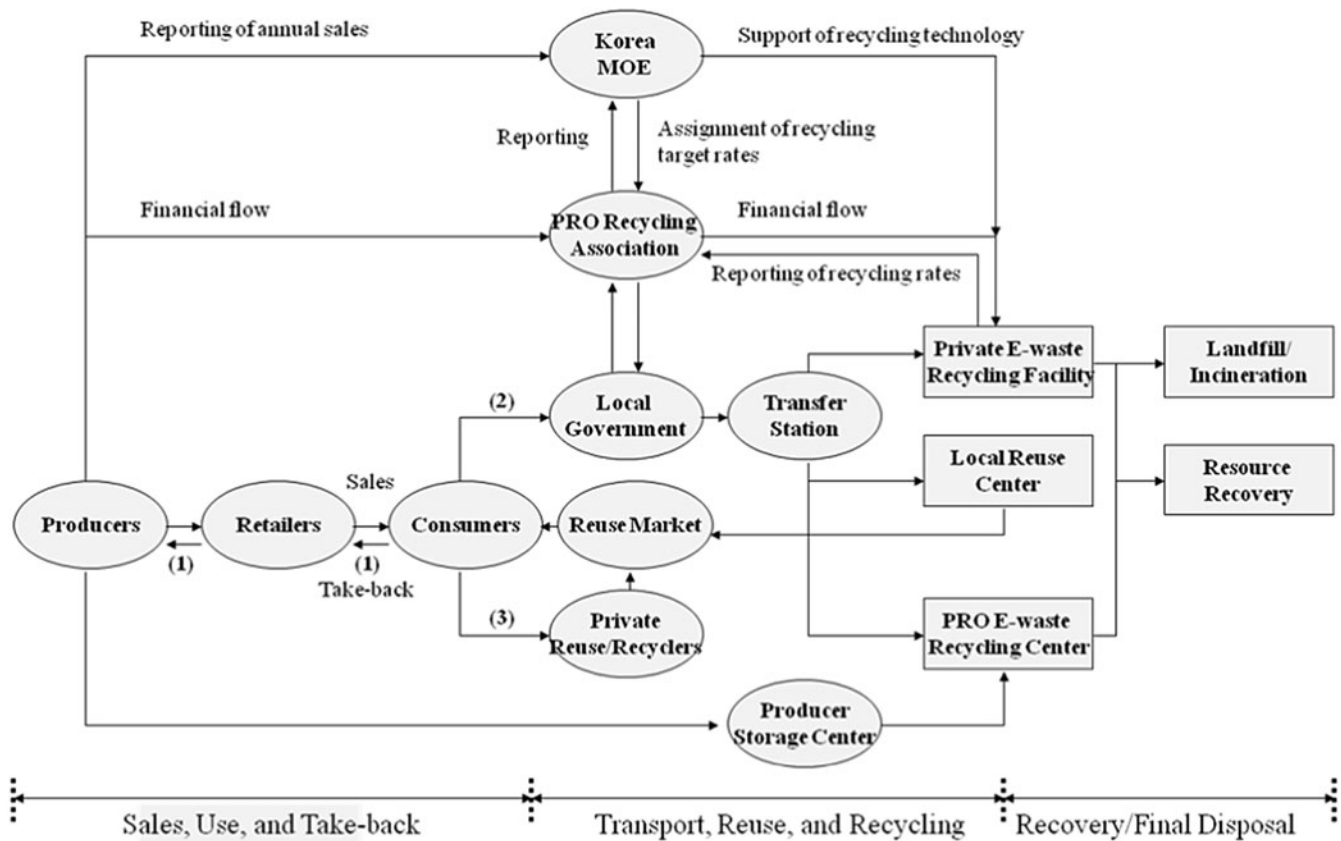


Fig 2. Waste electrical and electronic equipment (WEEE) collection and recycling system in Korea. MOE, Ministry of Environment; PRO, producer responsibility organization; 1–3, the three major collection pathways

requires producers to phase out the use of six hazardous substances (i.e., cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls, and polybrominated diphenyl ethers), to design “green” products, and to provide information on the components and hazardous substances present in electrical and electronic equipment for safe use and recycling as of January 1, 2008.

Recent WEEE regulation efforts, along with strict enforcement, should increase collection and recycling rates of WEEE through diverse collection programs, encourage manufacturers to develop more environmentally sustainable products, and require manufacturers to take extended responsibility for the recycling of their products. Restrictions on the use of the six aforementioned toxic chemicals in electrical and electronic products are critical for reducing potential environmental impacts during recycling and disposal. This measure should encourage manufacturers to reduce or eliminate their use of toxic chemicals and to design electronic devices compatible with reuse and recycling.

Collection and recycling systems of WEEE in Korea

Collection systems of WEEE

WEEE from consumers is typically collected via three major pathways in Korea, as shown in Fig. 2. The first

pathway is that electronic equipment producers, retailers, or suppliers usually take an old product from consumers free of charge when they purchase a similar new product (designated as (1) in Fig. 2). Producers, retailers, and suppliers are obliged to accept the old product and subsequently to transport it to producer storage centers. There are approximately 60 WEEE storage centers around the country that have been established by a number of manufacturers and importers of consumer electronics. Waste products are ultimately sent to producer recycling centers for material and resource recovery.

The second pathway involves local governments collecting end-of-life electronic equipment from households at designated areas or curbside collection points near residential complexes (designated as (2) in Fig. 2). Under this system, households have to buy a yellow sticker from the local government, stick it on the device, and place it in the designated area for obsolete electronic devices. The disposal fee ranges usually from US\$3–10 per device, depending on the type of electronic device. Local transporters contracted by local governments pick up the discarded electronics on a weekly basis and send them to either private WEEE recycling facilities, producer recycling centers, off-site treatment facilities, or local reuse centers.

Private collectors play a minor role in the WEEE collection system and often pay consumers for some electronic items (e.g., computers, televisions, and air conditioners)

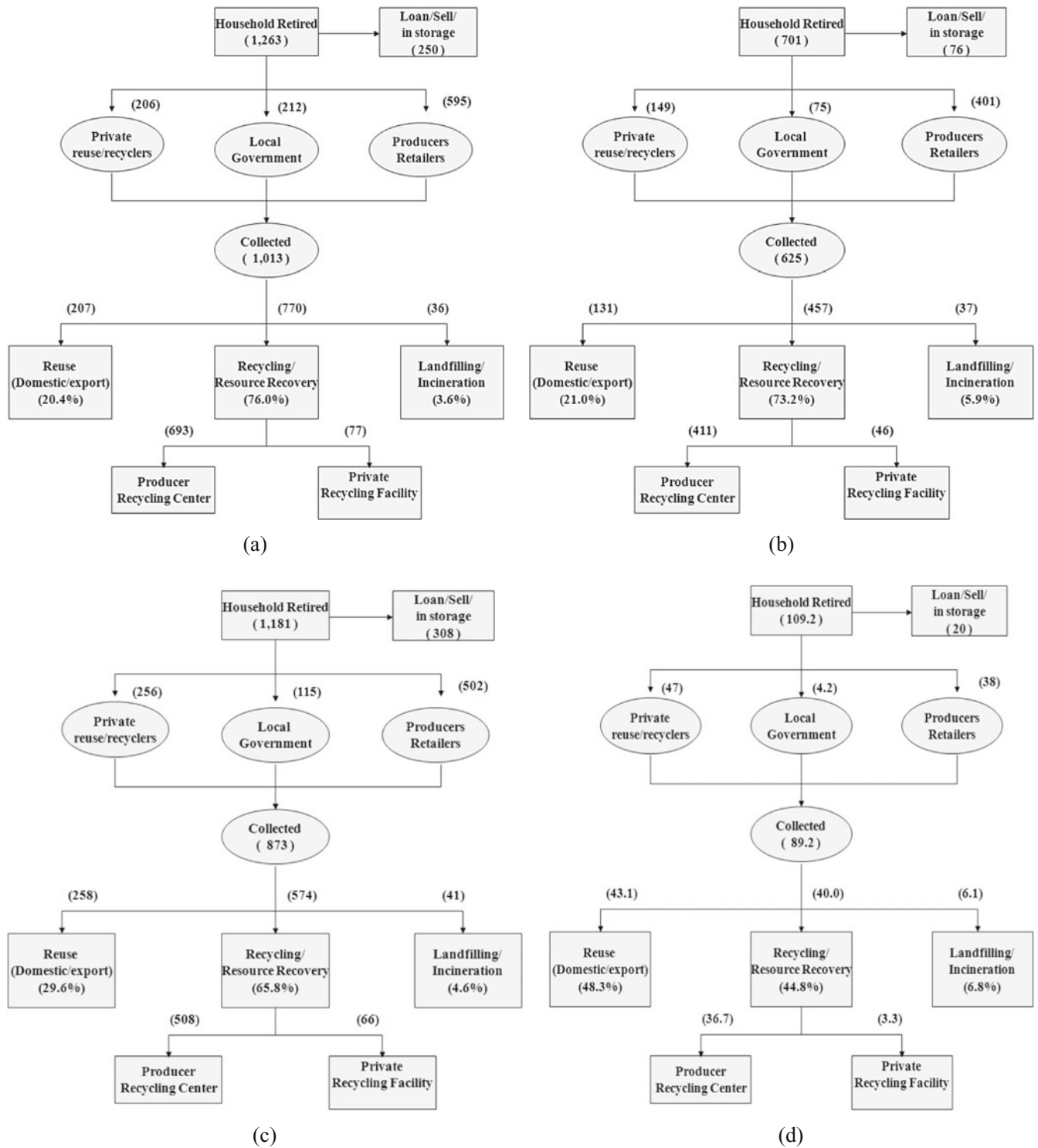


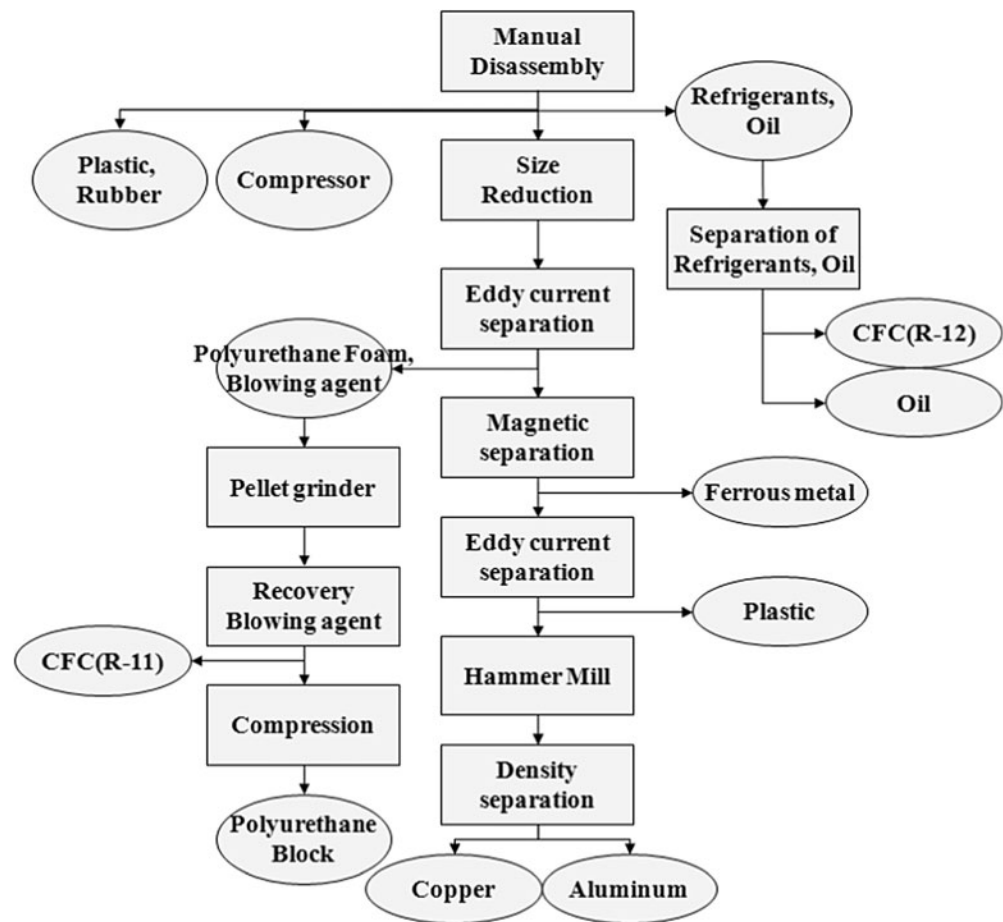
Fig 3. Material flow (in thousands of units) of selected WEEE categories: **a** refrigerators, **b** washing machines, **c** televisions, and **d** air conditioners in Korea in 2006

(designated as (3) in Fig. 2). They can generate revenue from reuse market dealers, private recyclers, or exporters by selling their collected electronic items and components.

Figure 3 shows the material flow of the selected WEEE categories (refrigerators, washing machines, televisions, and air conditioners) by the three major collectors (producers,

local governments, and private collectors and recyclers). A large proportion of each product is collected by producers/retailers, as shown in Fig. 3. Increased collection rates can be attributed to the implementation of EPR regulations. Collection activities of WEEE by local governments have been limited partly because of the lack of public awareness

Fig 4. Recycling processes for televisions, refrigerators, washing machines, and air conditioners at producers' electronic waste recycling centers in Korea. CFC, chlorofluorocarbon



regarding the importance of proper disposal of WEEE as well as the lack of the establishment of an effective WEEE collection network by municipalities. In addition, some obsolete electronic devices are commonly viewed as potentially valuable resources by residents. Only small amounts of the selected WEEE categories are landfilled or incinerated as shredded residues because landfilling and incineration of WEEE is commonly not accepted by local governments in Korea.

Recycling systems and processes of WEEE

Recycling of WEEE is important not only to reduce the amount of the waste requiring proper treatment and disposal, but also to promote the recovery of valuable resources. Valuable materials from obsolete electrical and electronic devices include ferrous metals, aluminum, and copper and can be recovered during material recovery processes at electronic waste facilities. In recent years, many developed countries have shown a great interest in establishing proper recycling processes to reduce the quantity of WEEE to be disposed of and to recover valuable resources.⁴⁶⁻⁴⁸

As shown in Fig. 3, Korea has two separate WEEE recycling systems: e-waste recycling centers run by producers and e-waste recycling facilities run by private operators. The

producer recycling centers (e.g., Yongin recycling center, Asan Samsung recycling center, Chilseo LG recycling center, and Honam recycling center) are managed by either Korea AEE or major electronics manufacturers. Such recycling centers mainly process large home appliances such as refrigerators, air conditioners, and washing machines (Fig. 3). The private recycling facilities around the country recycle smaller amounts of WEEE than the producers do, and often deal with televisions, mobile phones, computers, and other consumer electronic equipment. Recycling of these devices, however, is not well established, and accurate information on the recycling quantities and the procedures followed is largely unavailable.

Figure 4 shows the processes used to recover valuable materials (e.g., ferrous metals, copper, and aluminum) from WEEE at one of the producers' electronic waste recycling centers in Korea. The procedures typically include manual dismantling, size reduction, magnetic separation, eddy current separation, and cyclone separation. In the practice of recycling WEEE, as a first step, it is very common to manually dismantle obsolete consumer devices to recover highly valuable materials and to remove toxic materials. Since the composition of WEEE is diverse and complex in terms of components and materials, it is very important to identify both valuable materials and toxic substances. For example, cables, circuit boards, refrigerants, oils, and com-

pressors from refrigerators are manually removed in order to maximize the subsequent recovery of resources. A major concern of the current WEEE recycling process via dismantling, sorting, and other recovery processes is associated with uncontrolled emission of toxic chemicals (e.g., lead and polybrominated diphenyl ethers) to the surrounding environment.^{8,18} There are also potential health hazards from fumes, dusts, and harmful chemicals affecting the recycling workers who process the components. Information regarding the emission of air pollutants at WEEE recycling facilities in Korea is not currently available.

In Korea, the recycling of WEEE is still in its early stages in terms of recycling technology and infrastructure. Due to the high cost of WEEE transportation and recycling, as well as a lack of consumer incentives for collection, only a small fraction of WEEE is being recovered and recycled. Therefore, many obsolete electronic devices are waiting for disposal from home storage. For example, it is estimated that more than 28 million used and end-of-life mobile phones were stored in households as of the end of 2006.³¹

Suggestions and conclusion

Waste electrical and electronic equipment (WEEE) is one of the fastest growing waste streams in Korea. The proper management of such equipment has become of major concern for solid waste professionals because of the large growth of the waste stream and the presence of a myriad of toxic materials within it. The generation of WEEE has been increasing in quantity and variety due to the wide use and replacement of electronic devices. In the past, WEEE was often mixed with household waste and treated in incineration facilities or disposed of in municipal solid waste landfills. In recent years, increased public concerns over the improper disposal of WEEE have led to a movement to regulate the waste more systematically and stringently by the Korea Ministry of Environment (Korea MOE). Over the past few years in Korea, a number of regulations and guidelines, such as extended producer responsibility (EPR), have been developed to better manage WEEE from consumers and to establish an integrated electronic waste management system. Since many of the measures initiated by the Korea MOE have only recently started, their outcomes may still be difficult to evaluate. However, several suggestions can be made to improve current WEEE management practices in Korea.

First, public recognition of the need for WEEE collection and recycling should be greatly promoted. A major challenge for WEEE collection is related to a lack of consumer awareness of potential hazards that result from improper disposal of WEEE. Consumer awareness of appropriate handling, source separation, and disposal of WEEE should be a priority in municipalities; it is essential that consumers should recognize the potential impacts of WEEE on human health and the environment, if improperly managed. Waste minimization through source reduction, reuse, and recycling also has to be effectively implemented to decrease the amount of WEEE to be disposed of. Waste minimization

can be achieved by the following strategies: (1) encouraging consumers to purchase reusable electronic devices whenever possible (2) establishing effective policy for promoting the WEEE reuse market and recycling in collaboration with electronic waste recyclers.

Furthermore, one of the major challenges for WEEE recycling is the need to establish a proper collection system for a stable supply of electronic equipment to be recycled. It will be necessary to have continuous and stable demand for the recycled materials to establish the WEEE recycling industry. Especially, programs for WEEE collection by local governments have not been successful at promoting material recovery and recycling. They need to play a significant role in WEEE collection in municipalities by raising public awareness of the potential hazards of WEEE and the importance of WEEE recycling. Local governments should provide a place (municipal transfer facility) within the municipality where transporters contracted by the government can hand in consumer electronics to the recycling centers. Producers or importers should take discarded electronic products that have been collected by retailers and local governments and should transfer those products to recycling facilities for environmentally sound management.

More efforts have to be made to promote reuse and recycling of WEEE prior to final disposal, including economic incentive for collectors and development of recycling technology for various electronic devices. Recycling options should become a major part of WEEE management in Korea because incineration and landfilling are not currently accepted. Reuse and recycling of electronic equipment conserves energy and the precious materials contained in the equipment and reduces the environmental impact of these products upon disposal.

In recycling of WEEE, much work to date has focused on the recycling and recovery of materials from limited WEEE categories, especially refrigerators, washing machines, televisions, and air conditioners. According to the results obtained from this study, only small proportions of electronic devices covered by the EPR system are currently recycled. Thus, the EPR program needs to increase the target recycling rates to create an incentive to remove WEEE from storage. The recycling rates of other products such as computers, printers, and audio equipment are found to be even lower than those for the device categories mentioned above. This results partly from the lack of a sound and solid foundation for developing recovery and recycling techniques of the products. Thus, more efforts should be made to develop cost-effective recycling technologies. Since WEEE recycling can result in one of the greatest economic profits in the recycling industry, it would be valuable to study the potential and the dynamics of the WEEE recycling market.

Finally, categories and items in the EPR list, as promulgated by Korea MOE, need to be expanded to include small home appliances (e.g., vacuum cleaners and coffee makers) and other IT products (e.g., MP3 players and game players). Unlike the European WEEE system, current policy and regulation in Korea have focused on large home appliances

and limited IT products (e.g., computers, printers, and mobile phones), as regulated by the WEEE Act. Thus, very limited information and official data with regard to generation, electronic waste flow, and recycling of many other electrical and electronic devices are currently available. As some of the aforementioned emerging issues and problems associated with WEEE management become better understood, the findings could provide a basis for better environmentally sound WEEE management in Korea.

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