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Application of Delphi-AHP methods to select the priorities of WEEE for recycling in a waste management decision-making tool☆

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ABSTRACT

The management of waste electrical and electronic equipment (WEEE) or electronic waste (e-waste) has become a major issue of concern for solid waste communities due to the large volumes of waste being generated from the consumption of modern electrical and electronic products. In 2003, Korea introduced the extended producer responsibility (EPR) system to reduce the amount of electronic products to be disposed and to promote resource recovery from WEEE. The EPR currently regulates a total of 10 electrical and electronic products. This paper presents the results of the application of the Delphi method and analytical hierarchy process (AHP) modeling to the WEEE management tool in the policy-making process. Specifically, this paper focuses on the application of the Delphi-AHP technique to determine the WEEE priority to be included in the EPR system. Appropriate evaluation criteria were derived using the Delphi method to assess the potential selection and priority among electrical and electronic products that will be regulated by the EPR system. Quantitative weightings from the AHP model were calculated to identify the priorities of electrical and electronic products to be potentially regulated. After applying all the criteria using the AHP model, the results indicate that the top 10 target recycling products for the expansion of the WEEE list were found to be vacuum cleaners, electric fans, rice cookers, large freezers, microwave ovens, water purifiers, air purifiers, humidifiers, dryers, and telephones in order from the first to last. The proposed Delphi-AHP method can offer a more efficient means of selecting WEEE than subjective assessment methods that are often based on professional judgment or limited available data. By providing WEEE items to be regulated, the proposed Delphi-AHP method can eliminate uncertainty and subjective assessment and enable WEEE management policy-makers to identify the priority of potential WEEE. More generally, the work performed in this study is an example of how Delphi-AHP modeling can be used as a decision-making process tool in WEEE management.

1. Introduction

Once 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 in short). WEEE streams encompass a wide range of electrical and electronic waste products, including home appliances (e.g., refrigerators, washing machines, air conditioners); information technology and telecommunication equipment (e.g., personal computers, notebook computers, printers, copying equipment, calculators, facsimiles, telephones, mobile phones); consumer electronic devices (e.g., televisions, radios, video cameras, audio equipment); and other household electrical and electronic equipment (e.g., vacuum cleaners, toasters, coffee machines, hair dryers, watches, irons). WEEE is one of the fastest growing solid waste streams in many countries (Babu et al., 2007). The generation of WEEE has increased in quantity and variety due to the wide use and common replacement of electronic devices in this modern technology-driven society. As the life cycles of electrical and electronic products are becoming shorter, the quantity of WEEE is expected to increase in solid waste streams. Thus, proper management of WEEE has become a major concern for solid waste professionals because of the large growth of the waste stream as well as the presence of myriad toxic materials within it (e.g., lead,

☆ Summary: This paper presents the application of the Delphi-AHP method to determine the priorities of waste electrical and electronic equipment (WEEE) for recycling through the national waste management decision-making process in Korea.

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cadmium, mercury, polybrominated diphenyl esters) (Huo et al., 2007; Wong et al., 2007; Scharnhorst et al., 2007; Hidy et al., 2011).

In response to growing concern over WEEE, many countries are working to establish proper treatment and recycling processes to reduce the quantity of WEEE that is disposed and to recover valuable resources. Unlike municipal solid waste, WEEE management systems have not been well established in most countries. Many recent studies have been published to address potential problems associated with WEEE management (He et al., 2006; Liu et al., 2006; Musson et al., 2006; Babu et al., 2007; Kahhat et al., 2008; Yang et al., 2008; Jang, 2010; Hidy et al., 2011).

In 2002, the Korea Ministry of Environment (Korea MOE) modified the Act on the Promotion of Conservation and Recycling of Resources for effective collection and recycling of waste materials (Korea MOE, 2002). The Act went into effect in 2003, and Korea introduced an extended producer responsibility (EPR) regulation for packaging materials and electronic devices. The EPR requires producers to take more responsibility for managing the environmental impacts of their products throughout their life cycles. In 2007, the Act on the Resource Recycling of Waste Electrical Electronic Equipment (WEEE) and End-of-life Vehicles (ELVs) was enacted (Korea MOE, 2007). The Korea WEEE Act regulates six hazardous substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl esters) in electronics that disturb recycling and increase environmental impacts upon disposal, similar to the EU RoHS (the restriction of the use of certain hazardous substances) Directive (EU Directive, 2002a). However, the categories and types of WEEE regulated by the WEEE Act are still very limited and include only 10 electrical and electronic devices (i.e., refrigerators, washing machines, televisions, air conditioners, computers, printers, facsimiles, audio equipment, copy machines, and mobile phones). The EU WEEE directive consists of 10 categories with a total of 96 devices or types of equipment including large and small home appliances, information technology and telecommunications equipment, lighting equipment, medical devices, automatic dispensers, and others categories (EU Directive, 2002b). Unlike the European WEEE directive, current management policies and regulations in Korea have focused on large home appliances and limited IT products (e.g., computers, printers, mobile phones). The categories and items regulated by the EPR system under the WEEE Act need to be expanded, including small home appliances (e.g., vacuum cleaners, coffee makers) and other IT products (e.g., MP3 players, game players).

This study was intended to assess the potential of waste electronic devices or products that may become target WEEE for recycling and management in Korea. Four WEEE categories were selected for the evaluation process: new WEEE including large-sized home appliances, information and communication technology (ICT) devices, small and medium-sized household electronic devices, and audio and video equipment. Although these types of waste devices or equipment may not comprise a large proportion of WEEE streams, they merit special attention due to concerns over the hazards they pose to the environment upon disposal (Aizawa et al., 2008). Whether these devices or equipment should be included in WEEE regulations may depend on economic, environmental, and social factors such as the presence of proper recycling technology, generation rates (or emission rates), potential economic values, the presence of toxic chemicals and valuable metals, and the potential environmental impacts of the devices.

There is an urgent need to identify the ranking of new target WEEE for mandatory recycling and management in Korea. However, selecting an appropriate WEEE to be regulated can be a challenging and subjective task for waste management policy-makers, especially since waste management professionals and policy-makers often lack precise and objective decision-making procedures and evaluation criteria. Therefore, integrating objective and quantitative tools into the evaluation procedure enables decision-makers to efficiently and objectively identify the most appropriate WEEE to be recycled. In order to rank the target devices, we introduced the Delphi method and analytical hierarchy process (AHP) as a tool in the policy-making process for WEEE recycling. AHP modeling was used to determine the criteria weights and establish an evaluation model. The Delphi method was employed to identify objective evaluation criteria for selecting WEEE to be recycled.

A number of studies have examined the adoption of the AHP method for environmental management. Randall et al. (2004) adopted the AHP method for management of surplus elemental mercury in the US. Cram et al. (2006) used the AHP method to prioritize the same vegetation types based on endemic species. Hsu et al. (2008) utilized the AHP method to select the proper companies for medical waste disposal using interviews with medical waste experts by the Delphi method. Chang et al. (2009) combined the geographic information system (GIS) and fuzzy AHP method to search for the most appropriate distribution strategy in Taipei, Taiwan. Wang et al. (2009) used the AHP method to lower the complexity of waste management systems in order to select the appropriate solid waste landfill site. Lin et al. (2010) adopted the AHP method to determine the relative priorities of the addition of new mandatory recycled waste in Taiwan.

2. Background of WEEE management in Korea

The republic of Korea, with a population of approximately 50 million people, has experienced high environmental pollution loadings due to its rapid industrial development over the past several decades. The Korea's rapid economic growth, combined with its thriving electronics and information technology industry, fueled by such Korean electronics companies as SAMSUNG and LG, has become the major driving force for the expansion of domestic markets for electrical and electronic products. Recent statistics show that as of 2011, more than 52 million mobile phones, 24 million televisions, 17 million refrigerators, and 12.8 million computers were in use in Korea (KPE, 2012).

Determining life spans of electronic devices is central to estimating the potential rate of WEEE generation. Estimates are usually based on domestic demand for electronic devices and their average life span (i.e., the length of the time between the initial purchase of an electronic device and the time it completes its useful life). Life spans vary depending upon the type of device, economic and market conditions, age, and cultural behavior. It was estimated that the average life spans of the devices studied were 7.8 years for refrigerators, 7.8 years for washing machines, 7.4 years for televisions, and 6.0 years for air-conditioners. Shorter life spans were found for personal computers (4.0 years), notebook computers (4.0 years), printers (4.3 years), and mobile phones (2.4 years) (Jang and Lim, 2007; Jang, 2010).

By combining sales data (or domestic demand) with life span assumptions for each product, the total estimated number of units (or sometimes the corresponding weight) of a particular electronic device that is retired for waste management via reuse and refurbishment, recycling, export, or disposal (i.e., the amount of WEEE retired) can be estimated. The estimated amount of WEEE generated is determined by the sum of the retired amount of WEEE subtracted from the volume of WEEE that is reused, loaned, or stored at households. Based on the assumptions above, the retired and generated rate of WEEE in Korea can be estimated. For example, in this study, it was estimated that among 52 million mobile phones in use, more than 22 million mobile phones were

Table 1
Target recycling rates and accomplishment of WEEE recycling by the EPR system in Korea.

Type of WEEE	2009			2010			2011		
	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	222,474	45,830	58,636	234,430	51,809	64,618	231,792	57,948	62,568
Washing machines	95,470	24,918	26,046	107,136	29,356	29,215	97,884	27,897	27,885
Televisions	74,214	11,874	18,544	86,300	16,397	21,491	73,821	15,502	19,585
Air-conditioners	126,979	2921	2887	128,790	3091	3064	146,862	3525	4060
Computers	47,605	5284	8383	54,571	6712	9790	55,506	7771	7141
Audio equipment	4901	760	685	4667	793	711	4157	769	788
Mobile phones	3,206	635	629	3537	778	731	3302	759	619
Copying machines	4636	617	588	5732	814	994	5682	852	1002
Facsimiles	468	57	117	525	70	129	365	55	70
Printers	11,929	1420	1938	15,097	1963	2462	14,606	2191	2298
Total	591,882	94,316	118,453	640,785	111,783	133,205	633,977	117,269	126,016

Recycling target rates by EPR and the amount of WEEE recycled in Korea between 2009 and 2011.
Source: Korea KEC, 2012

retired in 2011 only, while more than 8 million of the mobile phones that were generated could be reused or recycled.

Table 1 presents the domestic demand, EPR target rate, and actual recycling rates of WEEE between 2009 and 2011 in Korea under the EPR system. The Korea MOE determine the annual mandatory recycling rate of each product, based on target recycling rates over the previous years, the amount of electrical and electronic products shipped from the warehouse, and recycling market conditions. The annual amount of EPR mandatory recycling rate is determined by the annual amount of electrical and electronic products that are sold in domestic market multiplied by the annual mandatory recycling rate. For example, in 2011, the Korea MOE determined that the amounts of recycling EPR target rates were 57,948 tons for refrigerators, 27,897 tons for washing machines, 15,502 tons for televisions, and 3,525 tons for air conditioners. The amounts of most WEEE products producers recycled generally exceeded their mandatory target rates.

Fig. 1 shows the trends of recycling rates of WEEE between 2006 and 2011. The quantity of WEEE recycled generally increased over the years because of the increased EPR target rate and regulation. The amount of WEEE recycled in 2011 was approximately 5.4% lower than the amount of WEE recycled in 2010. When compared with the average WEEE recycling rate (6.6 kg/person/yr) of advanced EU countries in 2010, the recycling rate (2.8 kg/person/yr) of WEEE in Korea as of 2011 is still much lower (EC, 2013).

In recent years, the national government and local governments have employed various methods to recycle WEEE. These include the establishment of collection systems for diverse e-waste devices, setting long-term national target rates for recycling of WEEE, assigning mandatory collection rates to electronics retailers and distributors, planning for the expansion of mandatory WEEE recycling by the EPR system, increasing the role of local government in WEEE collection, and developing a recycling technology roadmap for WEEE. If these WEEE collection and recycling efforts are improved, the amount of WEEE that is recycled will continually increase over time. Starting in 2012, some municipalities started to collect small and medium-sized WEEE in curbside collection containers free of charge in residential areas. In some municipalities, there is a free door-to-door collection service available for households who call on-line service to pick up large, obsolete household appliances by producers. In 2012, mandatory collection rates were assigned to larger electronics retailers and distributors for recycling of the 10 EPR items regulated by the Korea MOE. In 2013, the required collection rates for retailers range from 0.6% of air

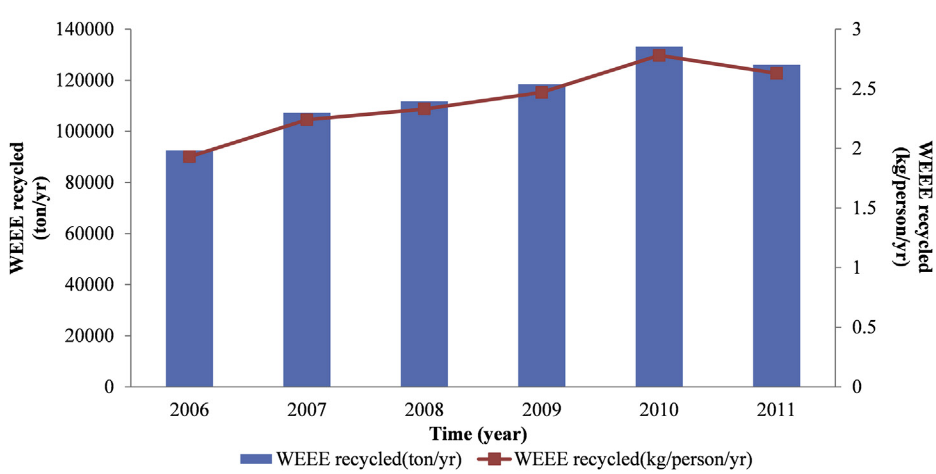

Fig. 1. Recycling rates of WEEE in Korea between 2006 and 2011.

conditioners to 25% of televisions that are sold to consumers (Korea MOE, 2013). In addition, there is growing interest in urban mining from WEEE in Korea due to rapidly increasing prices stemming from the depletion of valuable and rare metals (e.g., palladium, lithium, tin, cobalt, nickel, indium, titanium, neodymium, tantalum, and other metals) (Lee et al., 2007).

3. Methodology

In this study, the methodology included gathering data associated with annual domestic demand for (or sales of) selected home appliances and electronic devices, site visits, questionnaire surveys for the Delphi-AHP method, interviews and conversations, and a review of available literature. Site visits to locations including WEEE recycling centers and facilities, regulatory agencies, and the Korea Association of Electronics & Environment (Korea AEE), a producer responsibility organization (PRO), were made to support and supplement information gathered by the surveys. Interviews and conversations with environmental regulatory agencies, recycling industry experts, and PRO committees were conducted to obtain the details of recent progress and development associated with WEEE management. Available literature was also obtained and examined to compare WEEE collection and recycling rates in Korea with other countries and regions. An attempt was made to select the priority types of WEEE to be targeted for mandatory recycling in the EPR system in Korea. In addition to adopting the Delphi method to identify evaluation criteria, this study used the AHP to establish a model for selecting the priority devices. The theoretical approaches and backgrounds that were adopted are described below.

3.1. Delphi method

In this study, we used the Delphi and AHP methods to select products for the expansion and promotion of WEEE recycling in order to present priority rankings based on selected evaluation criteria. Our goal was to use the criteria and results as a basis to develop regulatory measures for the selection of products for inclusion in the expansion and maximization of WEEE recycling. We conducted an expert survey for appropriate evaluation criteria using the Delphi method, interviewing a total of 10 experts from government, academia, and industry sectors in order to prioritize products for WEEE recycling. Based on the evaluation criteria selected for priority ranking, the AHP method was used to determine the relative importance of each product. We also collected evidence from expert interviews, site visits, and the available literature on generation rates (waste volume or emission rate), recycling rates, valuable metal content, and ease of establishing a collection system.

To determine the evaluation criteria to prioritize the products, we applied the Delphi method. The Delphi method is used to repeatedly obtain expert opinions until there is a comprehensive consensus on selecting projects, predicting problems, and resolving problems (Delbecq et al., 1975). In contrast to the commonly used method of brainstorming, in which experts convene in one place to reach a consensus, the Delphi method overcomes the disadvantage of an outspoken person or collective group thinking dominating the outcome by allowing experts to respond anonymously. In this study, we primarily used e-mail to obtain opinions and conducted expert surveys twice (1st expert survey and 2nd expert survey). Specifically, we analyzed the coefficient of variation (CV) for the expert surveys and content validity ratio (CVR). In these evaluation criteria, when the CV value is less than 0.5, additional surveys are stopped (Dajani et al., 1979). The CVR developed by Lawshe (1975) and recalculated by Wilson et al. (2012) measures agreement among survey raters as to how essential a particular factor or item is. The CVR ranges from +1 to −1. A higher positive value is used as an indicator that survey experts were in agreement that a factor or item was essential. Generally, a CVR that is greater than 0.29 can be considered to be an appropriate evaluation level. The coefficient of variation is the ratio of the standard deviation to the mean. Using the CV can make it easier to compare the overall precision of the data obtained, as shown in Equation (1):

$$\text{Content Validity Ratio (CVR)} = \frac{\text{NE} - N/2}{N/2} \qquad (1)$$

where Ne = the number of survey experts indicating that a factor or item is “essential” and N = the total number of survey experts.

3.2. AHP method

When the environment is more complex and more factors need to be considered in decision-making process, it becomes difficult to select appropriate alternatives. Hence, in this study, we introduced the concept of hierarchical pair-wise comparison by applying the AHP method. By using AHP, the decision-making process can be divided into several hierarchical levels, and by using a pairwise comparison at each level, a decision can be made based on the knowledge and experience of many experts (Saaty, 1996). AHP assesses the priorities of multiple alternatives under various valuation criteria.

AHP calculates the relative importance of decision-making through stratification and class analysis. If the population to be studied is composed of many people, standards and periods, AHP is useful because it can separate these criteria during analysis. AHP uses class analysis and problem stratification to determine relative importance (Saaty, 1996). The classes of decision-making are determined-in the first phase, which may be the most important step in AHP application. The second phase collects evaluation data using pairwise comparison between decision-making factors, and also draws the matrix through pairwise comparison in a subclass that is dedicated to accomplishing the goals of each factor.

The next phase uses a matrix of pairwise comparison to estimate the weights and relative importance of the determination factors within each class. The $w_{1,}$ w_2, w_3, and w_n are calculated, indicating the effects and preference of valuation standards c_1, $c_{2,}$ c_3 and c_n by using the a_{ij} value acquired during the pairwise comparison. Saaty (1996) proposed the eigenvalue method as a weight evaluation, as shown in Equation (2):

$$A' \cdot W' = \lambda_{\max} \cdot W' \qquad (2)$$

where A is the square matrix resulting from pairwise comparison, $\lambda_{\max}$ is the maximum eigenvalue, and w is the eigenvector.

The measurement of consistency is developed using two characteristics. One is that matrix A has greater consistency as $\lambda_{\max}$ gets closer to n. The other is that $\lambda_{\max}$ values are always bigger than or the same as n, as shown in Equations (3) and (4):

$$\text{Consistency Index (CI)} = \frac{\lambda_{\max} - n}{n - 1} \qquad (3)$$

$$\text{Consistency Ratio (CR)} = \frac{\text{CI(Consistency Index)}}{\text{RI(Random Index)}} \qquad (4)$$

The random index is determined by the size of n. In cases when the consistency is perfect, $\lambda_{\max}$ is equal to n so that CI becomes 0 and CR is 0. On the contrary, as the consistency of judgments gets

Table 2
CV and CVR results of final evaluation criteria.

Criteria	CV	CVR
High waste generation rate or waste volume	0.14	0.80
Low recycling cost	0.24	0.40
Availability of recycling technology	0.15	0.56
High valuable metal content	0.20	0.80
Established collection system	0.13	0.40
Similarity to current Extended Producer's Responsibility (EPR) item	0.21	0.40
Similarity to current plastic disposal fee charge items	0.31	0.40

lower, λ_{max} becomes bigger than n and the CI and CR are both larger than 0. Saaty (1996) advised that CR is consistent in cases where it is smaller than or equal to 0.1. If it exceeds 0.1, the pairwise comparison needs to be done again or the questionnaire has to be revised.

In the last phase, the relative weights of decision-making factors are integrated to evaluate the total ranks of several different alternatives. The total importance of vectors that determine the priorities of alternatives at the bottom of the list are computed to achieve the purposes of determination at the top, which makes it possible to combine the weights of each class acquired in the third phase. The weighting equation of alternatives is shown in Equation (5):

$$\omega_i = \sum(\omega_j)(\mu_j^i) \quad (5)$$

ω_i : Total weight of the alternative i, ω_j : Relative weight of the valuation standard j, μ^i_j : Weight of the alternative i to the valuation standard j

In this study, we used the AHP method to collect expert opinions from the Korea MOE, academia, and industry sectors in the field of WEEE management and recycling. The AHP survey was administered to the experts; the results were analyzed and presented using Expert Choice 2000 software. If the importance of a specific evaluation criterion changes, the priority of product selection also can vary. Therefore, to determine the effect of the evaluation criteria on the results, we also performed sensitivity analysis for each criterion. These methods improve the efficiency of the decision-making process.

4. Results and discussion

4.1. Evaluation criteria by the Delphi method

We surveyed 10 experts in the field of WEEE recycling twice using the Delphi method in order to determine the evaluation criteria for prioritizing recycling of waste electronic and electrical products. Twelve criteria were selected by the first Delphi survey.

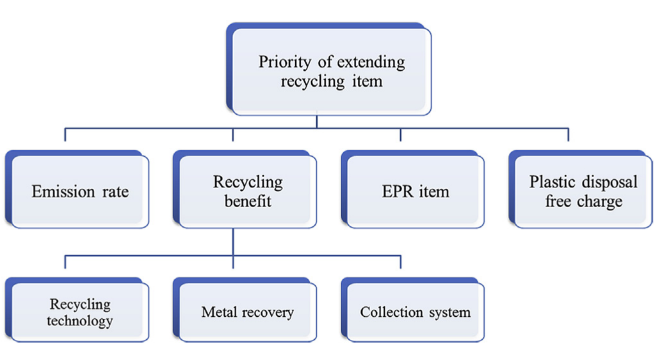

Fig. 2. Overall hierarchical structure of the AHP framework.

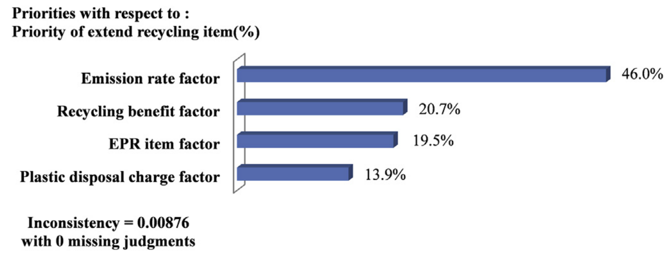

Fig. 3. Relative importance of 1st evaluation criterion.

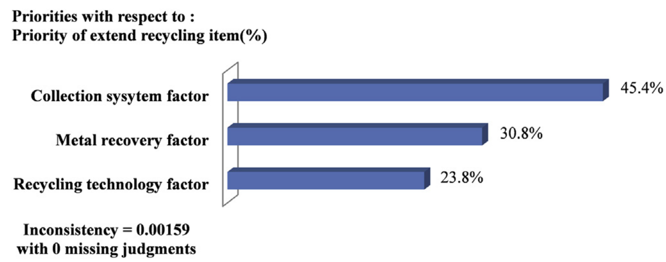

Fig. 4. Relative importance of 2nd evaluation criterion.

Seven final criteria were selected by the second Delphi survey, including high waste generation rate (or emission rate), low recycling cost, availability of recycling technology, established collection system, high valuable metal content (recovery potential), similarity to products regulated by current EPR items, and similarity to current plastic disposal fee charge items regulated by the Korea MOE. The CV and CVR results of the seven final criteria are shown in Table 2. Each evaluation criterion met the required levels of CV (less than 0.5) and CVR (greater than 0.29). Based on the results, similar criteria were grouped together hierarchically according to primary and secondary criteria, as shown in Fig. 2. In the hierarchical structure, the overall goal was to identify the priority of mandatory recycling items to be targeted. Level 1 (1st evaluation criteria) represents the four evaluation criteria (emission rate, recycling benefit, similarity to current EPR items, and similar products in the current plastic disposal fee charging system). Subcriteria (2nd evaluation criteria) under the recycling benefit include availability of recycling technology, higher valuable metal recovery, and establishment of a feasible collection system.

4.2. Results of AHP analysis

It is difficult to determine the priority ranking (importance) of each evaluation criterion by brainstorming or using the Delphi

Table 3
Products to be evaluated by the AHP method.

Category	Products
Large home appliances	Refrigerator, dryer, oven, water cooler/heater, freezer
IT and communication devices	Mobile (cellular) phone, electronic dictionary, scanner, telephone
Audio/video equipment	Television, camera, DVD, projector, portable GPS device, MP3 player, portable multimedia player, electric musical instruments, game console, home theater system
Medium-sized or small consumer electronics	Vacuum cleaner, microwave oven, electric rice cooker, heating fan, electric fan, air purifier, humidifier, dehumidifier, bidet, electrical mixer, coffee maker, electric iron, table lamp or stand

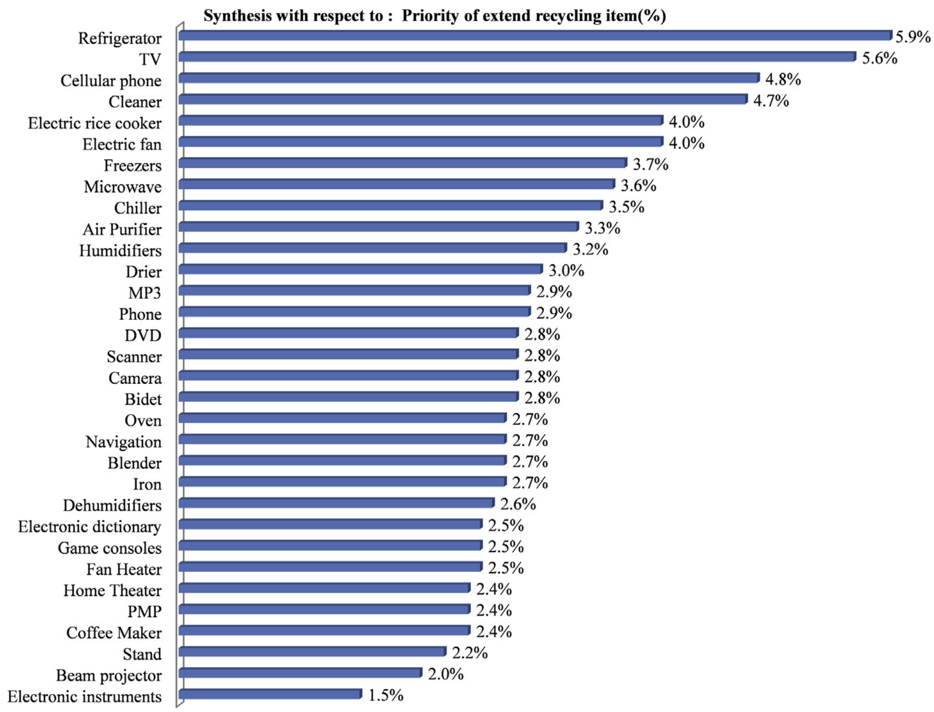

Fig. 5. Priority of WEEE to be recycled with relative importance.

method. However, by using AHP analysis, the relative importance of each evaluation criterion can be quantified and can ultimately lead to the selection of alternatives (in this study, the priority ranking of alternative products to be recycled). The relative importance of each evaluation criterion was determined, as shown in Fig. 3. The results showed that the emission rate or generation rate was the most important factor with a weighted percentage of 46.0%, followed by the recycling benefit factor (20.7%) and similarity to products currently regulated by the EPR item (19.5%). Therefore, in order to minimize the effort and time spent in the process of prioritizing the products, the factor to be considered first is the emission rate or generation rate. Fig. 4 shows the relative importance of the secondary evaluation criteria that were determined to be subordinate to recycling benefit, using the AHP method. Similar to the results listed above, the collection system is a very important factor (45.5%), followed by metal recovery (30.8%) and recycling technology (23.8%).

Before starting the AHP method, the Korea MOE suggested 32 potential WEEE candidates to be prioritized during expert interviews, as shown in Table 3. Among these, three EPR products (i.e., refrigerators, TVs, and mobile or cellular phones) were also included in expert surveys for the relative comparison of products with future mandatory target recycling items. Based on the primary and secondary selection evaluation, the results of the priority ranking of the products are listed in Fig. 5. After being evaluated for relative importance, the 32 products in Fig. 5 were ranked according to their overall priority among recycling items. In addition to the three current WEEE that have been targeted for recycling (refrigerators, TV, and mobile phones), the top ten priority items to be added to the mandatory target recycling EPR list include vacuum cleaners, electric fans, electric rice cookers, large freezers, microwave ovens, water purifiers, air purifiers, humidifiers, kitchen dryers, and telephones in order (from the first to the last).

Table 4 presents the top ten priority ranking results based on the factor only, with all factors considered. The emission rate or generation rate was considered to be the most important factor in this analysis. The results show that when only the emission rate or generation rate is considered, it is optimal to include vacuum cleaners, electric fans, electric rice cookers, microwave ovens, telephones, humidifiers, freezers, camera, electric irons, and water coolers/heaters (in order from first to last) in the expansion of recycling target items. When all the factors are considered, the top five priority items include vacuum cleaners, electric fans, electric rice cookers, freezers, and microwave ovens.

Table 4 also shows the top 10 priority items by the "generation rate or emission rate" factor, comparing them with actual generation rates of small-size electronics and appliances (in order from first to last) by unit and mass reported by other researchers (Kim

Table 4
Priority ranking among products considered for expanded recycling.

Rank	By all factors	By waste generation rate or emission rate	Waste generation rate (by mass)[a]	Waste generation rate (by unit)[a]
1	Vacuum cleaner	Vacuum cleaner	Vacuum cleaner	Telephone
2	Electric fan	Electric fan	Electric mixer	Vacuum cleaner
3	Electric rice cooker	Electric rice cooker	Electric fan	Electric mixer
4	Freezer	Microwave oven	Electric rice cooker	Electric fan
5	Microwave oven	Telephone	Telephone	Electric rice cooker
6	Water purifier	Humidifier	Humidifier	Humidifier
7	Air purifier	Freezer	Microwave oven	Microwave oven
8	Humidifier	Camera	Coffee maker	Electric iron
9	Kitchen dryer	Electric iron		
10	Telephone	Water purifier		

[a] Source: Kim et al., 2008.

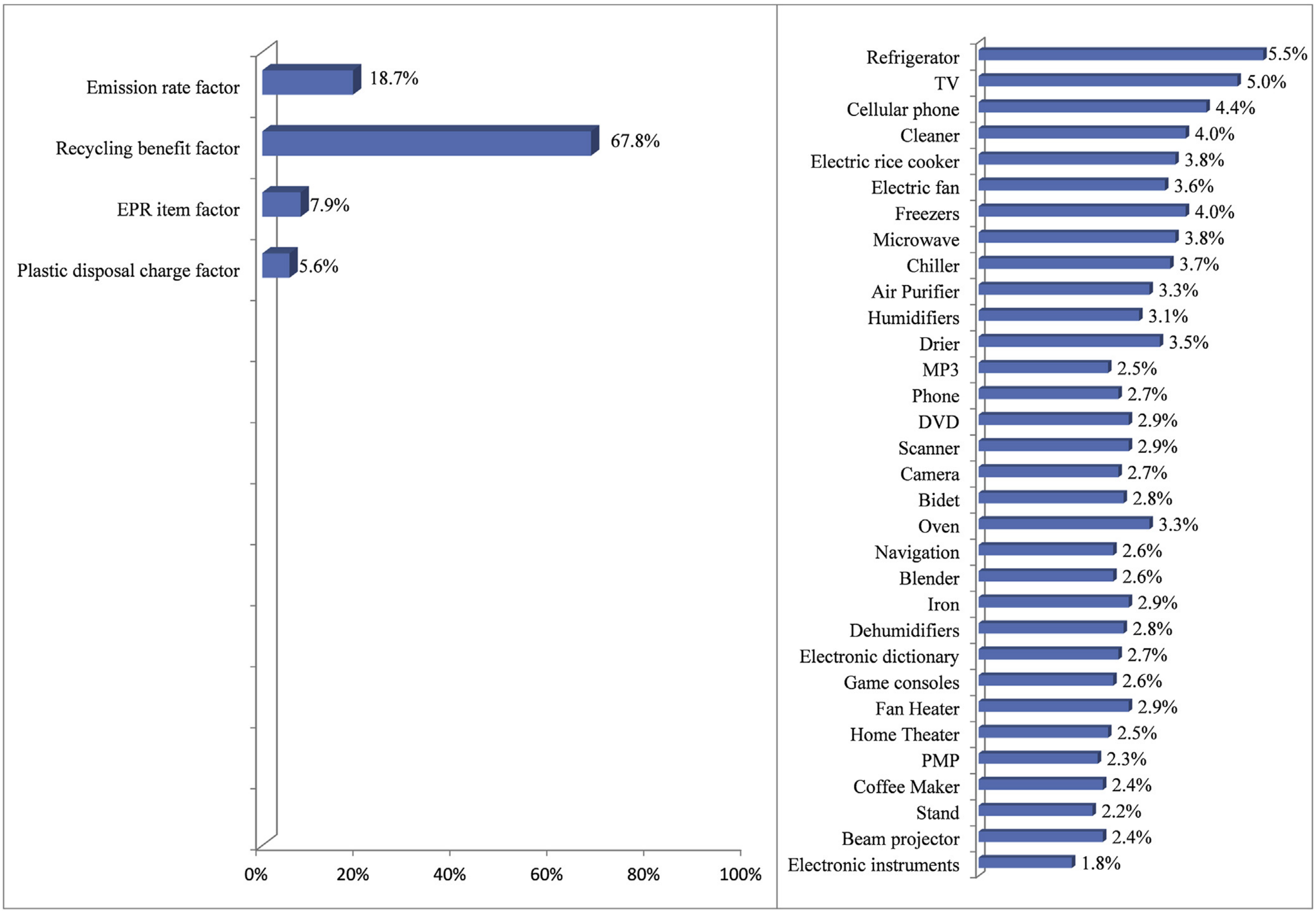

Fig. 6. Results of sensitivity analysis with respect to changes of relative importance of evaluation criteria.

et al., 2008). It is found that the order of the top 10 products in our study is very similar to that of the generation rates of small appliances reported by Kim et al. (2008) (Table 4).

4.3. Results of sensitivity analysis

To improve the decision-making process, sensitivity analysis was used to analyze the way changes in the importance of factors affect on the results. For example, if the importance of the recycling benefit factor increases from 20.7% to 67.8%, the priority ranking of products to be included in the expansion of target recycling items also changes, as shown in Fig. 6. Vacuum cleaners, large freezers, electric rice cookers, microwave ovens, water purifiers, electric fans, dryers, air purifiers, electric ovens, and humidifiers have been identified as the top ten items in order from first to last. Thus, the priority ranking results have also changed due to the change in the importance of the factors.

In the coming years, the Korea MOE plans to add 16 new categories of WEEE to be mandatorily recycled by the EPR system, based on the results of this study as well as a series of discussions among stakeholders (e.g., producers, NGOs, the recycling industry, and government). The target items to be considered for mandatory recycling include water purifiers, air purifiers, vacuum cleaners, microwave ovens, bidets, electric rice cookers, heating fans, electric fans, humidifiers, electric irons, electric cookers, kitchen dryers, video cassettes, electric mixers, food waste drying machines, and water softeners.

5. Conclusion

In an ever-changing modern electronic and information technology society, numerous electrical and electronic devices are generated for consumption and eventual disposal. In order to effectively increase WEEE recycling rates imposed by the WEEE Act, the target WEEE list should be gradually expanded, based on social infra-structure and consensus among stakeholders. However, selecting an appropriate WEEE to be regulated for recycling and proper treatment is frequently a challenging and subjective task because waste management decision-makers often lack precise and objective data and evaluation criteria.

In this study, we used the Delphi method and AHP to determine the priority of target recycling products for the expansion and promotion of WEEE recycling. Expert surveys were performed to determine the evaluation criteria and expand the list of EPR products to be mandatorily recycled. Evaluation criteria were first selected based on the results of the primary and secondary Delphi surveys; the results were classified hierarchically, grouped by similarities. The primary evaluation criteria included generation rate or emission rate (46.0%), followed by recycling benefit (20.7%), and similarity to products currently regulated by the EPR system (19.5%). The secondary evaluation criteria were collection system (45.4%), followed by valuable metal content (30.8%) and recycling technologies (23.8%). Applying the above criteria using the AHP, the results indicate that the top 10 target recycling products for the expansion of the WEEE list were found to be vacuum cleaners, electric fans, electric rice cookers, large freezers, microwave ovens, water purifiers, air purifiers, humidifiers, kitchen dryers, and standard telephones in order from first to last.

The application of Delphi and AHP modeling proved to be an efficient tool for the WEEE decision-making process. Integrating quantitative methods into the evaluation procedure enabled decision-makers to determine WEEE priorities for recycling objectively and efficiently. Recent WEEE regulation efforts along with better recycling technology would increase WEEE collection and recycling rates through diverse collection programs, encourage producers to develop more environmentally sustainable products, and require producers to take extended responsibility for the recycling of their products. Finally, it should be noted that the relative importance of evaluation criteria used in WEEE analysis can change due to better collection systems, innovations, and new recycling technologies. Therefore, this study's evaluation criteria and the factors used to determine its relative importance should be updated and further refined for evaluation in waste management arena.

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