Waste Management 33 (2013) 474–483

Contents lists available at SciVerse ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Estimating the amount of WEEE generated in South Korea by using the population balance model

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ARTICLE INFO

Article history:
Received 23 March 2012
Accepted 3 July 2012
Available online 11 August 2012

Keywords:
Waste electrical and electronic equipment
Lifespan distribution
Population balance model
Collection rate

ABSTRACT

We estimated the amount of waste electrical and electronic equipment (WEEE) generated in South Korea by using the population balance model (PBM) based on a lifespan distribution analysis. This is the first study to apply PBM to estimate WEEE generation in South Korea. The lifespan distribution analysis of electrical and electronic equipment (EEE) was based on the results of a questionnaire survey of 1000 households, which were analyzed with the Weibull distribution. As a result, we could estimate the domestic service lifespan and lifespan distribution shape parameter for eight selected products. Using the lifespan distribution analysis and other data, such as the shipment volume and the number of products owned by households, we estimated the amount of WEEE generated for the eight selected items from 2000 to 2020. We found that 1.2 million air conditioners, 2.5 million televisions, 1.3 million microwave ovens, 1.2 million kimchi refrigerators, 17.0 million mobile phones, 1.7 million refrigerators, 2.0 million vacuum cleaners, and 1.4 million washing machines were generated as WEEE in 2010. We also compared our WEEE estimates with the number of items collected through the official WEEE recycling program from 2003 to 2009 and found that in 2009 washing machines had the highest collection rate (28%) and air conditioners had the lowest rate (7%).

1. Introduction

In 2003 South Korea instituted a mandatory recycling program for waste electrical and electronic equipment (WEEE) based on the principle of extended producer responsibility (EPR); (OECD, 2001). According to the Act on the Recycling of Electrical and Electronic Equipment and Vehicles (MOE, 2008), producers have a duty to collect a minimum percentage of WEEE as determined by the government in proportion to the amount of new electrical and electronic equipment (EEE) shipped to the market in that year.

To assess the EPR policy properly, monitoring and meaningful targets are critical (Sheehan and Spiegelman, 2006), and reliable data on the amount of WEEE generated are essential. However, there are no official statistics for annual WEEE generation or collection in South Korea; thus, it is not obvious how much WEEE has actually been collected through this program, especially as a percentage of total amounts generated. In addition, uncertainties in the quantity of WEEE generated have also caused disputes about collection targets. More specifically, electronics manufacturers have suggested that collection targets should be set on the basis of the amount of WEEE generated and not on current product shipments (AEE, 2008). In the same context, the European Committee of Domestic Equipment Manufacturers stated that the collection target of its WEEE Directive should be based on waste stream relevance because there are time differences between the products' placement on the market and its removal from service, depending on the particular characteristics of the product (CECED, 2010). The European Parliament and the Council of European Union agreed that the methodology for calculating collection rates based on WEEE generated should be developed in the near future (European Parliament and Council of EU, 2012). To have a realistic understanding of current collection performance and to set appropriate future performance goals, high-quality estimates of the amount of WEEE generated are necessary. In South Korea, there have been a few attempts to estimate the quantity of WEEE generated, but the methodologies used have been limited, as is discussed in Section 2.

The purposes of this study were to estimate the annual amount of WEEE generated in South Korea from 2000 to 2020 for eight products and to estimate the annual percentage of WEEE collected through the EPR recycling program from 2003 to 2009.

2. Previous estimates of WEEE generation in South Korea

We found seven previous studies of WEEE generation in South Korea in academic journals, reports from research institutions,

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http://dx.doi.org/10.1016/j.wasman.2012.07.011

Table 1
Previous estimates of WEEE generation in South Korea.

Author	Year	Methodology	Estimation objects (years)
KSWM	1998	Outflow (t) = inflow (t-average lifespan), where t = year	Desktop PCs, televisions (1998–2030)
AEE	2005	Discard rate × number of households	Air conditioners, copiers, mobile phones, PCs, PC monitors, printers,
AEE	2006		refrigerators, washing machines (2005)
Lee et al.	2007	Outflow (t) = inflow (t-average lifespan)	Air conditioners, televisions, refrigerators, washing machines (2000–2005)
KSWM	2007	Aggregating the collected volume of WEEE through a questionnaire survey of WEEE collectors	Air conditioners, televisions, refrigerators, washing machines (2006)
KEI	2009	Σ inflow $(t-i)$ × discard rate (i), where i = product age	Air conditioners, PCs, refrigerators, televisions, washing machines, mobile phones (2000–2015)[a]
Jang and Kim	2010	(Shipment volume – number of new subscribers) × 60%	Mobile phones (2000–2007)

[a] Mobile phones was handled with the same methodology to Jang and Kim (2010).

and EEE producers' organizations (Table 1). Among the studies, KSWM (1998) and Lee et al. (2007) estimated WEEE generation from sales data and product lifespan information. This type of estimation model, the "delay model" (Van der Voet et al., 2002), has been widely applied to the estimation of WEEE generation. KSWM (1998)used the model to estimate the number of waste desktop PCs generated from 1998 to 2030 using an assumed lifespan, and Lee et al. (2007) used the model to estimate the amount of WEEE generated for four end-of-life household electronic appliances from 2000 to 2005 on the assumption that the average lifespan of the four items was about 10 years. In both cases, the lifespan was assumed, not derived from empirical data. AEE (2005, 2006) used the discard rate and number of households to estimate the quantity of WEEE generated. AEE conducted a questionnaire survey targeting the discard rate and household characteristics of approximately 1800 respondents. Some characteristics that could have an influence on discard rate, such as household income and number of household members, were not considered in the survey, and the report did not verify whether the questionnaire surveys were biased. Therefore, it is questionable whether the calculated WEEE discard rates are representative values for South Korea. KSWM (2007) calculated the amount of WEEE generated for four items by aggregating the amount collected through questionnaire surveys of WEEE collectors. Unfortunately, informal WEEE collectors were not included, and the estimated WEEE quantities may therefore be underestimated.

Jang and Kim (2010) estimated the number of end-of-life mobile phones generated from 2000 to 2007 by subtracting number of new subscribers from the number of phones purchased domestically in each year. On the basis of the results of a questionnaire survey, they assumed that 60% of the estimated number of end-of-life mobile phones were actually discarded and 40% were permanently stored at home by the user (i.e., they were "hibernating"). However, these hibernating mobile phones are almost certainly eventually discarded. Thus, Jang and Kim (2010) may have underestimated the actual amount of WEEE generated.

KEI (2009) calculated the amount of WEEE generated for six items from 2000 to 2015. The number of end-of-life mobile phones was estimated with the same methodology as Jang and Kim (2010). The amounts for the other five products were estimated based on the discard rate, which was assumed as the normal distribution. The discard rate was calculated simply by dividing the number of discarded products per product age through the total number of discarded products in the recycling centers. This estimation method is limitedin that the average lifespan is affected by the number of products shipped in the corresponding shipment year (Oguchi et al., 2010). Therefore, the average lifespan reported by KEI (2009) may have been affected by the size of past shipments. In addition, future shipment volumes were assumed to maintain2008 shipment levels.

Research on WEEE generation has different advantages and disadvantages depending on the estimation model used (Wen et al.,2009). In this study, we applied the population balance model (PBM), which has been applied in many academic studies (e.g., Kakudate et al., 2000; Tasaki et al., 2001, 2004; Daigo et al., 2005; Oguchi et al., 2006; Yamasue et al., 2009; Yoshida et al., 2009). The main reason for using PBM is that over estimation and underestimation of WEEE generation are less likely because the model draws on the mass balance principle of inflow (shipment volume), outflow (waste volume), and stock (ownership volume). Also, it is a time-series material flow analysis model so that it enables the estimation of past and future WEEE generation. However, PBM is facing limitations when estimating products of fast growth phase or decline stage on the market, because the parameters of lifespan distribution for those products might vary.

3. Methods and materials

3.1. Estimation objects

As of August 2011, the WEEE recycling program of South Korea included the following 11items: air conditioners, copiers, computers (desktop and laptop), fax machines, mobile phones, printers, stereos, televisions (includingflat-screen and cathode-ray-tube televisions), refrigerators, kimchi refrigerators, and washing machines. (A kimchi refrigerator is a product designed only for storing kimchi, a traditional Korean fermented vegetable product.) The recycling program is expected to gradually expand to include all types of EEE (MOE, 2010).

One of the purposes of this study was to estimate the collection rates of the recycling program based on the amount of WEEE generated for each product. Therefore, we targeted products included in the Korean recycling program. Some items with low rates of ownership in Korean households were excluded (e.g., fax machines, 0.02 unit/household and copiers, 0.07 unit/household) (KPE, 2009) because it would have been difficult to gather a sufficient amount of samples from the questionnaire survey of households without conducting a survey on a large scale. Desktop PCs were also excluded because some are assembled by PC stores. These desktop PCs circulated in the market (Lee, 2008) and are thus not included in the published shipment statistics. According to Lee (2008), the number of the assembled desktop PCs was equivalent to 20% of the total number of desktop PCs' shipment in 2008. However, as there is no further information available, the shipment volume for the other years could not be estimated. With the exception of desktop PCs, the assembled EEE were not reported in South Korea. We included microwave ovens and vacuum cleaners in the estimations because they have a high rate of household ownership