Resources, Conservation and Recycling 120 (2017) 65–74

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Full length article

Portable battery lifespans and new estimation method for battery collection rate based on a lifespan modeling approach

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ARTICLE INFO

Article history:
Received 18 May 2016
Received in revised form 11 January 2017
Accepted 12 January 2017
Available online 7 February 2017

Keywords:
Lifespan
Portable battery
Recycling
Material flow analysis
Batteries directive
Weibull distribution

ABSTRACT

Separate collection and recycling of used batteries is required in the EU member states and other countries, as a measure for environmentally sound management of batteries. Monitoring of collection rate of the separate battery stream is important for decision making, in particular for implementing interventions to improve the separate collection and evaluating their results. Limitations of the currently applied method for the estimation of battery collection rate are discussed and a new method, which improves the estimation, is suggested. The method utilizes a more accurate way of estimating the total battery waste generation. This estimation is based on batteries historical consumption estimated with material flow analysis method and distributions of batteries lifespan obtained from empirical data.

Empirical data from two decades of battery consumption and disposal in Sweden were analyzed and lifespan distributions have been found for eight different types of batteries by dating over 5000 disposed batteries. The lifespans stretched from 1 to 28 years, with a median lifespan of 3–8 years.

It is shown how the use of lifespan distributions in the suggested method could considerably improve the estimation of the collection rate. Consequently, the intervention potentials can be identified more accurately and the decision making for investments in the collection system can be improved. The observed lifespans are also useful for understanding batteries fate in households as well as trends in battery consumption and disposal.

1. Introduction

Due to their significant content of both valuable (Ag, Ni, Zn) and hazardous (Hg, Cd and Pb) metals, batteries are one of the priority products for protection of the environment and resource recycling. Proper management of used batteries is becoming increasingly important due to the exponential growth in the consumption of batteries which is driven by the use of portable electronic equipment (Guevara-García and Montiel-Corona, 2012; Kalmykova et al., 2015a,b,c; Patricio et al., 2015a). The current management approach in the EU member states, as well as in Japan and Australia and some other countries, is to separate the collection of batteries from other waste streams.

Majority of batteries used by households are portable batteries. Portable batteries are all sealed batteries and accumulators with weigh less than 3 kg that are not classified as automotive batteries, accumulators, industrial batteries or accumulators or batteries for electrical bicycles (Directive 2006/66/EC). The collection of portable batteries in Europe is regulated in Directive 2006/66/EC, which requires member states to achieve a collection rate of 45% by 2016. Sweden has defined a more ambitious collection target of 75% by 2016. According to statistics from the Swedish Environmental Protection Agency (EPA), 60.7% of the portable batteries sold in Sweden in 2015 were collected (Swedish EPA, 2016).

Large investments are being put into the infrastructure for separate collection of batteries as well as consumer education and collection campaigns. For example, in Sweden two ambitious nation-wide programs that included direct information and cultural interventions (music, TV, cinema, children's theater) have been implemented in 1987 and 1999. In 2012, a 10 million Euro information program was launched from the Swedish EPA battery fund for information purposes. Many of the decisions on the necessary improvements in the battery collection are based on the measured collection rate with respect to the defined collection target.

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http://dx.doi.org/10.1016/j.resconrec.2017.01.006

Currently available method for the estimation of the batteries collection rate can be found in The Battery Directive (Directive 2006/66/EC). The Directive 2006/66/EC defines the collection rate as "... the percentage obtained by dividing the weight of waste portable batteries collected [...] in that calendar year by the average weight of portable batteries that producers sell [...] during that calendar year and the preceding two calendar years" (further referred to as "the Directive method"). However, this method of estimation can lead to implausible results, as in the case for NiCd batteries collection in Sweden, where collection rate has been estimated to be in the range of 300–1500% for the years 2009–2015. Therefore, it is important to re-examine the assumptions of the Directive method and the possible impacts of them on the accuracy of the collection rate estimation. It is also of importance to improve such estimations, if possible.

In this paper, we propose to use an approach similar to the methods used for the estimation of the Waste Electrical and Electronic Equipment (WEEE) generation: the Input-Output analysis method, as described in Wang et al., 2013 and to the lifespan modeling method as described in Oguchi et al., 2008 (Wang et al., 2013; Oguchi et al., 2008). In this study, the lifespan is set to the domestic service lifespan, defined as the period of time from initial manufacture until the point in time when a product is disposed of by the final owner (Murakami et al., 2010). According to Magalini et al. (2014), the Input-Output analysis and, in particular, the use of the sales or MFA time-series data together with lifespan distributions was considered as the most appropriate methodology to calculate WEEE waste generation for all the EU member states. The noncomplex calculation process, as well as the high potential of harmonization across the countries in Europe, are some of the advantages highlighted. The batteries collection rate could then be estimated by dividing the weight of batteries collected in a given year by the estimated total disposal in the same year, this estimation performed by applying the lifespan distributions.

Up to date, only one paper on waste batteries generation has been published. The waste battery flows for China were estimated using annual sales data as well as probable lifespan distributions of various batteries, obtained from relevant literature (Song et al., 2016). In that paper it is assumed that all primary (non-rechargeable) batteries in China are consumed within a year, and the average lifespan of secondary batteries vary from 3 to 6 years, depending on the chemical composition of the battery. On the other hand, actual lifespan distributions would give better precision in the results. Such study of batteries empirical lifespans has been conducted for Belgium, where the average lifespan of primary batteries (alkaline) was found to be 5 years (Desmet and Mertens, 2014).

The purpose of this study is to contribute to development of estimation methods for batteries collection rate. This is done by studying the lifespans of batteries in order to: 1) understand the lifespan of different primary batteries; and 2) develop a new estimation method for battery collection rate using lifespan data.

2. Theory

The collection rate is defined in this paper as the proportion of the batteries during a certain year that were disposed of through the separate collection system for batteries (further – "correct disposal"). Explicitly,

$$CR_t = \frac{C_t}{W_t} \quad (1)$$

with CR_t = collection rate in year t, C_t = amount of correctly disposed batteries in year t, W_t = total amount of disposed batteries in year t.

The amount of correctly disposed batteries each year can be obtained from public statistics. The total amount of disposed batteries, however, is unknown and needs to be estimated.

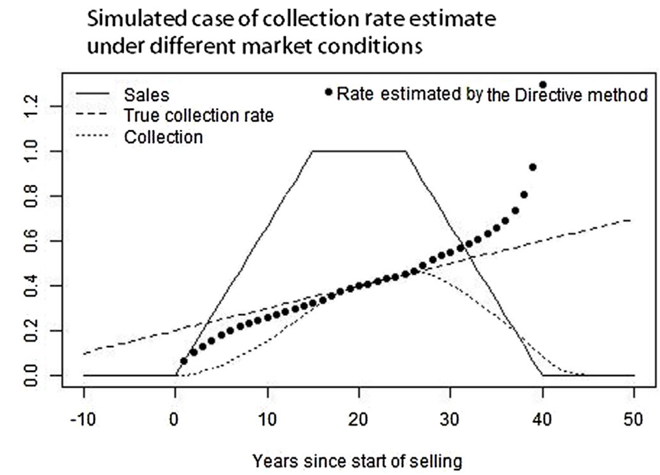

Fig. 1. Simulated case of the collection rate estimation by the Directive method.

The methodology, currently applied in the EU (the Directive method) uses the average of batteries sales during the last three years as an estimate of the total amount of disposed batteries in year t. Intuitively, such an approach is accurate only if sales are constant from one year to the next. Usually, this is not the case and a more sophisticated methodology that takes into account the change in sales over time might be needed.

The alternative method of estimating the total amount of disposed batteries that we propose in this paper can be briefly outlined as follows.

Let S(t) be the amount of batteries that are put on the market in year t. We hypothesize that these batteries will have a certain service lifespan i.e. time to their ultimate disposal, through separate collection or otherwise. This lifespan will not be deterministic, but, rather, follow a probability distribution with a cumulative density function that we denote as F(i). This would mean that, of all batteries sold year t, S(t)*(F(1) – F(0)) will be disposed of the same year, S(t)*(F(2) – F(1)) the year after and so on. This, in turn, would mean that the total amount of batteries that is disposed year t would be a mixture of batteries that were sold several years prior, weighted with the probability that the batteries will be disposed of during a particular year. Explicitly, Eq. (2):

$$W_t = \sum_{i=0}^{\infty} S(t-i) * (F(i+1) - F(i)) \quad (2)$$

with W_t = total amount of disposed batteries in year t, S_t = the amount of batteries that are put on the market in year t; F(i) = probability distribution.

Observe that we can view the methodology currently applied in the EU (the Directive method) as a special case of the approach suggested in this paper, with either sales S(t) assumed to be constant or lifespan distribution to be uniform. Such assumptions seem too strict, as there is evidence that the batteries lifespans can be different from 3 years and vary depending on the batteries type or chemical composition (Guevara-García and Montiel-Corona, 2012; Desmet and Mertens, 2014).

To illustrate the impact of violation of these assumptions, we might consider a simulated example of sales and disposal of batteries, where the sales first increase, then stay stable and then decrease while the battery lifespan follows a Weibull distribution (see Eq. (3)). In the literature, Weibull cumulative distribution function is often used to model lifespans of consumer products, in particular WEEE (Melo, 1999; Elshkaki et al., 2005; Polák and Drápalová, 2012). Consider Fig. 1. In this figure, the solid line indicates the sales, the dotted line – the correct disposal and the dashed line