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Differences of methods to estimate generation of waste electrical and electronic equipment for developing countries: Jordan as a case study

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ABSTRACT

This paper examined pros and cons of five methods of estimating generation of waste electrical and electronic equipment (WEEE). The study considered WEEE generated from the household sector and aimed at discussing the applicability of the methods to developing countries. For this purpose, Jordan was used as a case study in the Middle East and the North Africa (MENA) region. The total and individual amounts of six types of WEEE generated in Jordan, including both firsthand and secondhand were estimated. The Consumption and Use (C&U) method, which has been widely employed in developing countries because parameters needed are a few and easy to obtain, was modified. The modifications addressed its drawback in which it underestimates the amounts of WEEE. The study showed that most of the compared methods provided similar estimates of the total WEEE amounts but dissimilar results for each appliance. Each method has to be applied with careful consideration of the market conditions (e.g. saturated or unsaturated). For instance, the original C&U method can be applied to a condition of a fully saturated market. Here, the method's assumption is each household owns, at least, one appliance shared by the household members. The Simple Delay method can be applied to a fully saturated market, where the Time Step and the Mass Balance methods apply to both saturated and unsaturated markets. The Approximation 2 method overestimates the amount of WEEE, but its suitability is for a fully saturated market.

1. Introduction

Waste from electrical and electronic equipment (WEEE; also known as e-waste) is becoming one of the fastest-growing waste streams worldwide. A new report written by Baldé et al. (2015) shows that the global WEEE generation quantity in 2014 was around 42 Mt, where 12 Mt was generated in Africa and 16 Mt in Asia with an annual growth rate of 4% to 5%. According to the report, the MENA region produced 2.4 Mt of WEEE with an average of 8 kg/person/year that varies between 0.9 kg/person/year and 17.2 kg/person/year. The estimation included 19 countries in the region for a total population of around 400 million.

Perez-Belis et al. (2015) conducted an in-depth literature review on WEEE management research. The authors observed that one of the major concerns of the literature was alarming WEEE growth due to accelerated technological advances and high obsolescence and rapid electrical and electronic equipment (EEE) consumption rates. The authors observed that WEEE generation was the main issue researched in the literature. The authors concluded there was a lack of standardized methods for their estimation in several countries.

In this paper, Jordan's data was used to estimate Jordan's WEEE generation amounts and to compare different estimation methods. The purpose is to understand the advantages and disadvantages of methods that have been frequently used to estimate WEEE for their application to developing countries. Thus, (1) different WEEE estimation methods were compared and (2) current WEEE generated in Jordan and the potential future WEEE as a case of the countries in the MENA region were estimated. Based on the results, the comparison between the methods was discussed. The paper also discussed in which conditions and under which assumptions each method can be applied to.

With respect to the MENA region, very few comparative studies were available (Seitz, 2014). Except two countries, Morocco, and Tunisia, no complete national inventory exists in the Arab countries. The scarcity of available data, experience, and technical support made it difficult to conduct an inventory in many MENA countries and Jordan. For instance, Fraige et al. (2012) conducted a questionnaire and interviews to estimate the total WEEE amount generated in Jordan, but the generation of secondhand products was not an interest of the study. The EEE examined included TVs,

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Table 1
Examples of studies that applied the C&U method in developing countries.

Study	Type	EEEs	Geographical location
Laissaou and Rochat (2008)	National assessment report	Televisions, computers, and mobile phones	Morocco
Gurauskiene and Stasiskiene (2011)	Peer-reviewed paper	Refrigerators, freezers, washing machines, dishwashers, electric cookers, microwaves ovens, vacuum cleaners, electric irons, personal computers, mobile phones, TVs, video recorders/players, and video/photo cameras	Lithuania
Chung et al. (2011)	Peer-reviewed paper	Non-plasma and non-liquid crystal displays televisions, refrigerators, washing machines, air conditioners, and personal computers	Hong Kong
Araújo et al. (2012)	Peer-reviewed paper	Refrigerators, washing machines, televisions, freezers, and audio systems	Brazil
Alavi et al. (2015)	Peer-reviewed paper	Refrigerators, freezers, televisions, washing machines, dishwashers, audio systems, air conditioners, desktop computers, monitors, laptop computers, mobile phones, telephones, and lamps	Iran

mobile phones, PCs, refrigerators, washing machines, air conditioners, microwaves, electronic games, and other EEE categories, such as printers, scanners, toys, etc. Their study revealed that Jordan produced 23,400 t of WEEE from these EEE in 2010 from the household sector. However, the mathematical formula used in the study was not explained, and the results cannot be justified or compared with other studies. This study is the first systematic and comprehensive study for an Arabian country in the MENA region that attempted to compare different estimation methods for the case of developing countries and to estimate WEEE based on the comparison.

2. Review of WEEE estimation methods

Many studies were conducted to estimate WEEE generation in developed and developing countries. Several peer-reviewed studies that applied to developing countries were reviewed to understand (1) the reason for each method selection, (2) the appliances that were selected for WEEE estimation and (3) the methods of data collection. In the following sections, five estimation methods and their advantages and disadvantages and the required data for each method are discussed.

2.1. Model A: Consumption and use (C&U) method

The C&U method was employed in the Netherlands to estimate the WEEE amount (Widmer et al., 2005). The C&U method (Eq. (1), it has also been referred to as Approximation 1) requires stock data in the current evaluation year and average lifespan. Stock quantities can be calculated by multiplying the number of households by the saturation level per household. The saturation level is defined as the percentage of households that owns, at least, one EEE, and its maximum value is one. Dividing the stock by the average lifespan gives the WEEE amount generated (in tons) in an evaluation year t. The method's formula is presented in Eq. (1), in which $H(t)$ is the number of households, $N_h(t)$ is the saturation level per household, W is the average EEE weight and, L is the average lifespan.

$$\mathrm{WEEE}_W(t) = \frac{H(t)N_h(t)W}{L} \quad (1)$$

This method might be useful in countries where data are scarce, and no inventory of WEEE exists. In such a case, the method can provide a rough estimation with minimal data requirement. The C&U method is described in EEA (2003), Widmer et al. (2005), UNEP (2007), Schluep et al. (2012), Lau et al. (2013), and Li et al. (2015). Many studies applied the method in the context of developing countries. Examples of such studies are presented in Table 1. In the recent literature, the method was applied by Araújo et al. (2012) in Brazil by using national statistical data to estimate WEEE from saturated market products: refrigerators, washing machines, TVs, freezers and audio systems. The reason for the method selection seems to be its applicability for saturated products. The authors applied both the C&U and the Time Step methods for saturated and dynamic markets; whereas, in a dynamic (unsaturated) market, technology is changing rapidly and demand for products is growing faster than in a saturated one.

2.2. Model B: Time step method

The Time Step method estimates WEEE based on sales and stock data. The change of stock is the difference between the stock in the current evaluation year and the previous year. Potential WEEE is represented by Eq. (2), WEEE equals sales minus the difference between stock inflow and outflow where $S(t)$ is the sales, and $\mathrm{St}(t)$ is the current stock quantities in a year t. This method provides good results for a fully saturated market in which it treats saturated EEE equally. The required stock data can be obtained from national statistics. Sales data can be obtained from Eq. (3).

$$\mathrm{WEEE}(t) = S(t) - \left\{\mathrm{St}(t) - \mathrm{St}(t-1)\right\} \quad (2)$$

$$S(t) = I(t) + P(t) - E(t) \quad (3)$$

where $I(t)$ is the import quantities, $P(t)$ is the production quantities, and $E(t)$ is the export quantities at evaluation year t.

The method was also used by Araújo et al. (2012) to estimate potential WEEE from mobile phones and personal computers. The reason for method selection seemed to be its applicability for the dynamic market, and the data used were gathered from national statistics.

2.3. Model C: Simple delay method

In the Simple Delay method, the WEEE generation in a year t is equal to historical sales data in a $t-L$ year. The Simple Delay method can be used in a fully saturated market or products where the population is stable, and it cannot capture the sudden change in technology in which a new-generation product replaces an EEE. The method's advantage is that the calculation can be carried out easily where the required data range is simple. Sales data can be obtained from import, production, and export of EEE (Eq. (3)). The method is presented below.

$$\mathrm{WEEE}(t) = S(t-L) \quad (4)$$

The method was applied by Jain and Sareen (2006) (referred to as the Market Supply method) to estimate the theoretical amount of WEEE in India for TVs and personal computers where data were obtained from the industry association. According to the authors,