Journal of Cleaner Production 133 (2016) 262–271

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Product flow analysis using trade statistics and consumer survey data: a case study of mobile phones in Australia

Artem Golev [a, *], Tim T. Werner [b], Xuan Zhu [c], Kazuyo Matsubae [d]

[a] Sustainable Minerals Institute, The University of Queensland, St Lucia, QLD 4072, Australia
[b] Environmental Engineering, Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia
[c] School of Earth, Atmosphere and Environment, Faculty of Science, Monash University, Clayton, VIC 3800, Australia
[d] Graduate School of Engineering, Tohoku University, Japan

A R T I C L E I N F O

Article history:
Received 3 May 2016
Accepted 22 May 2016
Available online 27 May 2016

Keywords:
Mobile phone
Product flow analysis
In-use stocks
Product lifespan
Consumer survey
Australia

A B S T R A C T

This study describes an integrative approach to product flow analysis of (waste) electrical and electronic equipment using trade statistics and consumer survey data. We demonstrate this approach with a case study of mobile phones. Using statistical and empirical data for Australia over 1997–2014, we have shown how different sources of information can be collated and cross-checked to estimate the product in-use stocks and flows, product lifespan and lifespan structure, as well as to detail the product age structure in stock and at the end of life.

From our results, the total number of mobile phones in in-use stocks in Australia has been estimated at 46 million at the end of 2014, or about 2 phones per capita. The proportion of phones kept in storage (not being in use) has been constantly rising, reaching 50% in 2012–2014. The average expected lifespan for a mobile phone sold in Australia decreased from about six years in the late 1990s to about five years in the early 2000s, and then stabilised at around four years (±0.5 years). The average time of active use for mobile phones was estimated in the range of 2.0–2.6 years (which includes first use and reuse). The estimated lifespan profile for mobile phones in Australia has been confirmed to be relatively similar to that reported in Japan.

While this methodology presented here provided meaningful results, the accuracy and relevance would be improved by better quality of original data. Therefore, in conclusion, we also highlight potential improvements in consumer surveys that would help to enhance the analysis.

1. Introduction

Electronic products such as mobile phones, laptops, TVs and tablets utilise the physical properties of highly specialised and geochemically scarce metals to function. These metals (e.g. Ag, Au, In and many others) must be mined and refined, sometimes at significant environmental and social cost, to be integrated into these products. Yet many electronic products are wasted at the end of their useful lives, appearing in landfill or in some cases illegally exported to developing nations, fostering further economic, environmental and social problems for these countries (Balde et al., 2015). The recovery of valuable components in electronic products has attracted significant interest in recent years as a means to reducing these risks (e.g. Li et al., 2015; Pickren, 2014), particularly amidst growing environmental impacts and regulations facing the mining industry (e.g. Mudd, 2010). However, the economic recovery of metals from e-waste requires some understanding of the location, composition and volume of products available for future extraction, so that investments into recovery operations can be properly informed. Approximations and modelling are necessary to obtain such information in the absence of direct measurement and reporting.

The materials in electronic products, and indeed all metals in society, whether active in use or dormant and not yet disposed of, are known as 'in-use stocks'. In-use stocks have been indirectly or directly estimated through various approaches and methodologies, each with different emphases, for example in input–output accounts, national capital accounts, life-cycle assessments (LCA) and material flow analyses (MFA) (Pauliuk et al., 2015). Within the MFA studies, there are two primary approaches by which in-use stocks

* Corresponding author.
E-mail address: a.golev@uq.edu.au (A. Golev).

http://dx.doi.org/10.1016/j.jclepro.2016.05.117
0959-6526/

of products or their contained materials have historically been estimated: top-down and bottom-up. The top-down approach essentially entails the collection and analysis of data on material inputs and outputs for a specified system. The difference between inflows and outflows (e.g. imports plus domestic production minus exports) over a specified time period can indicate in-use stocks via mass balance. The bottom-up approach entails the collection of data on the number of products/commodities within a given area and summing these to estimate the total in-use stocks.

Both the top-down and bottom-up approaches have advantages and disadvantages. For example, while bottom-up studies permit the spatial distribution of in-use stocks to be estimated, they are often temporally restricted to one year. Here, top-down studies can shed more light as they permit multi-year analyses and hence trends in stock accumulation, although they often rely on highly aggregated data that do not relate to specific products, and are further problematic to disaggregate spatially. These and other methodological uncertainties are described in numerous previous studies, e.g. (Chen and Graedel, 2015a; Gerst and Graedel, 2008; UNEP, 2010).

The multi-year analyses under the top-down approach are referred to as Dynamic MFA (DMFA) and have been applied to describe historical material flows and stocks of various metal resources. Several DMFA studies have projected possible future developments and related resource flows at both national and global levels based on scenarios. Muller et al. (2006) and Wang et al. (2007) focused on the anthropogenic iron and steel cycle, Daigo et al. (2007) estimated both the in-use and the total steel stock, which includes hibernating stock in Japan, and Reck et al. (2008) analysed the nickel stock and flows at the national and global scale. While the above studies have focussed on specific metals, other MFA studies have emerged which focus on the flows of specific products. Oguchi et al. (2008) analysed the circulation of major consumer durables in Japan, Harper (2008) analysed global flows of tungsten-containing products, and Chen and Graedel (2015b) estimated in-use stocks of 91 products in the United States.

Studies in MFA have additionally used monetary Input Output (IO) tables even for relatively small flows; an example is found in the work of Nakamura et al. (2007). IO analysis is one of the most widely used tools for describing economy-wide activities and their environmental implications (Suh, 2009). IO based MFA models, for example Waste IO-MFA, analyse the compositions of the materials or substances in products and scrap. Nakamura and colleagues provided several studies on IO based MFA (Nakamura et al., 2008, 2009; Ohno et al., 2014). Nakamura et al. (2014) also provided a worthy methodological framework, MaTrace model to enable visual tracking of the fate of materials whether accumulated in in-use stocks or dissipated in waste streams. In addition, Wang et al. (2013) provided a detailed overview of different IO models used for product flow analyses and e-waste estimation.

If elements of multiple MFA methodologies are applied to the same commodity under the same system boundaries, more can be revealed about the nature of that commodity. For example, both the spatial distribution of the commodity and potential trends over time in stock accumulation could be determined, and further the uncertainty associated with each method could be compared and interpreted. Very few studies have conducted multiple assessments, e.g. both top-down and bottom-up assessments of the same commodity or product, with Hirato et al. (2009) being a notable example. This is likely due to the time taken to conduct MFA studies, and given that regardless of the specific MFA method employed, almost all MFA studies must contend with a lack of up to date and spatially relevant data. Indeed, it is relatively accepted that the contribution offered by an MFA study is that it synthesises available data to characterise the flows of a new commodity, and/or to represent previously un-studied spatial/temporal aspects, but not necessarily that it employs raw data collection.

The limited data sources which are available for MFA studies can often be re-used through multiple generations of studies, which ultimately become less spatially and temporally relevant to the source data. For several electronic products including mobile phones, we have seen increases in value and utility, and considerable hoarding behaviour developed (ACMA, 2015; Read, 2015), which affects the in-use stocks and average lifespans of the products. There are therefore considerable uncertainties for future projections of e-waste volumes associated with using fixed product lifespan and distribution parameters (e.g. Weibull function) based on previous investigations. Furthermore, the limited number of studies currently used to inform in-use stock behaviour may provide source data that is spatially explicit (i.e. reflecting usage behaviour in a certain country), making them problematic to infer for other locations.

Empirically collected data, which reflects the system boundaries of the MFA study itself, can assist in reducing these uncertainties, and hence this study focuses on how such data can be integrated into multiple methods of product in-use stocks and flows estimation. In the following sections we describe this approach in detail and demonstrate its application with the case study of mobile phones in Australia.

2. Methodology description

Estimating (waste) electrical and electronic equipment ((W)EEE) circulation is a difficult task due to often low quality and incomplete data, meaning that multiple assumptions are required for input–output modelling (Wang et al., 2013). The annual sales of EEE (in monetary value and units) are usually well recorded through national and international systems and institutions (e.g. UN Comtrade database), while the information on in-use stocks and end-of-life (EoL) products is not directly documented. To uncover the latter, detailed consumer (and institutional) surveys, information from professional associations and authorities (e.g. telecommunication regulatory bodies), recycling and waste management companies data, as well as special investigations are needed (Fig. 1).

The top-down approach in this study uses aggregated information at the country level. The modelling of in-use stocks and flows in this approach can be solely based on trade statistics. Using estimations of products average lifespans from previous studies allows an approximation of the overall circulation of (W)EEE in the economy (Balde et al., 2015). However, for many EEE categories the lifespans significantly differ over time and/or between countries. The up-to-date (dynamic) country/region based information derived from bottom-up approaches can significantly improve and/or help validate the modelling.

The overall approach to estimating the circulation of mobile phones in this study is presented in Fig. 2. Most individual parts of this approach are generic and can be applied to any EEE, however the integration of top-down and bottom-up components is permitted by the available data, which is an uncommon feature in MFA. The system boundaries for this study are limited by EoL products generation, although the (historic) consumer surveys also indicate the likely pathways for mobile phones at the end of life.

Our methodology first requires the compilation of two major datasets: sales and in-use stocks, based on trade statistics and consumer surveys accordingly. The information on mobile services subscriptions can be used for comparative purposes to support the mobile phones in active use estimation. The number of EoL phones (outputs) can be estimated via mass balance between inputs (phone sales) and in-use stocks for every respective year.