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Where do all the metals go? Indium and neodymium flows from emerging technologies in Switzerland

Abstract: *Electronic equipment (EE) contains important material resources, including bulk materials, precious metals, and critical raw materials such as indium (In) and neodymium (Nd). For an efficient management of these resources, it is important to know where the devices are located, how long they are used and when and how they are disposed of. In this article, we explore the fate of critical raw materials in EE and thus the suitability of their in-use stock for urban mining. With a special focus on the service lifetime, storage time and disposal pathways of different device types, we investigate the past and current quantities of EE containing In and Nd in the stock and quantify the flows between the use, storage and disposal phase. Results highlight the importance of the storage stock, which accounts for 25% of the mass of the total stock in 2014. Electronic devices in Switzerland represent an In stock of over 2 tons and a Nd stock of 38 tons.*

1 Introduction

Bulk material and precious metals in electronic equipment have been recovered in Switzerland for the last 20 years. Several critical raw materials such as indium (In) and neodymium (Nd) are not recycled but lost in the waste management process. In is mainly used as indium-tin-oxide in flat screen displays. Nd is primarily used in magnets for e.g. hard disk drives or loudspeakers (Böni et al. 2015). Solutions to recover critical raw materials from EE are in its infancy. They are hampered by low concentration per device, low market prices that make recycling unattractive, limitations of recovery technologies as well as limited knowledge on stocks and flows of these devices (van Schaik and Reuter 2010; UNEP 2013). Dynamic material flow analyses (MFAs) are often used to analyze the development of material stocks and flows over time. The product lifetime and the subsequent past and future stocks and flows of electronic devices, are modeled in dynamic MFAs mostly by assuming lifetime distribution functions for the devices in the in-use stock.

In this article, we present a dynamic MFA of nine different types of EE containing In and Nd in Switzerland. We develop a model to identify past and current in-use stocks and storage stocks and quantify in detail the flows between and from the use, storage and disposal phases. Based on the in-depth ‚bottom-up' data we are able to differentiate between new and (re)used devices. Since existing data are incomplete and scarce, we evaluate associated data uncertainties.

2 Method

Data for the service lifetime, storage time and disposal pathways were collected via a survey and interviews (Thiébaud et al. in press). Devices included are mobile phones, desktop and laptop computers, monitors, cathode ray tube (CRT) and flat panel display televisions (FPD TVs), DVD players and headphones. Based on the survey's results, the system for the dynamic MFA was developed as a cascade model, with each step consisting of an in-use-stock and storage stock for new and used devices, respectively (Figure 1). Sales flows are taken from annual ICT market reports (Thiébaud et al. 2016). The uncertainty of sales flows were modeled as normal distributions. The standard deviation (SD) was estimated at 10%, 20% or 30%, depending on the data source (Thiébaud et al. 2016). In order to estimate the lifetime distribution functions for the dynamic MFA, we fitted Weibull distribution functions to the normalized histograms of the service lifetimes and storage times of new and second-hand devices, taken from Thiébaud et al. (in press). The transfer coefficients, again taken from Thiébaud et al. (in press), were modeled as triangular distributions. The mass and metal concentration per device type base on various data sources (MoE and METI 2010; IUTA and fem 2011; Sander et al. 2012; Buchert et al. 2012; Westphal and Kuchta 2013; Ueberschaar and Rotter 2015; Böni et al. 2015; Thiébaud et al. 2016) and were also modeled as triangular distribution. With a specially developed software tool we use Monte Carlo simulation to calculate the stocks and flows depicted in Figure 1, including all associated uncertainties.

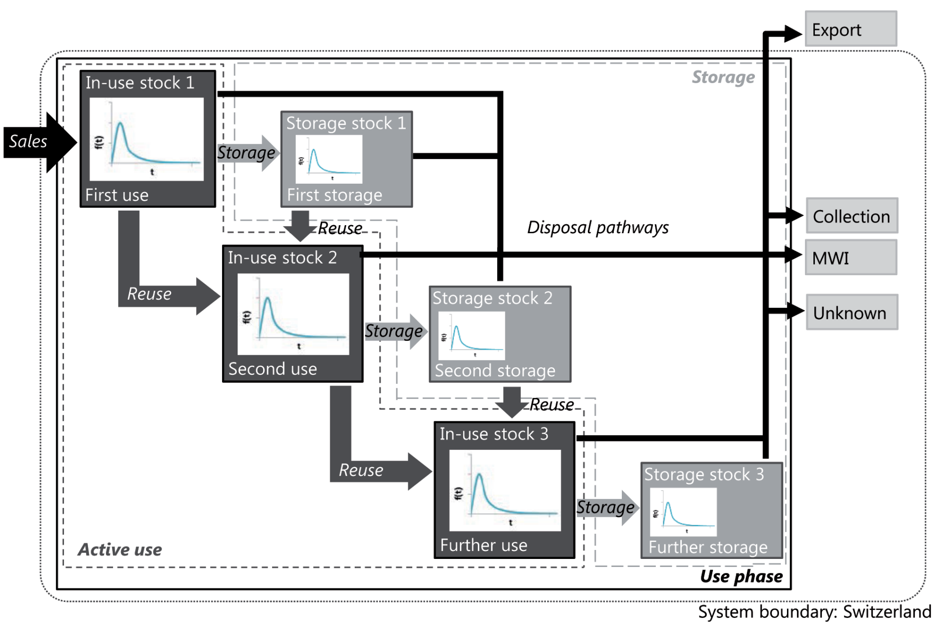

Figure 1: Cascade model of the process 'use phase' (Thiébaud et al. 2016).

3 Results and discussion

The cumulated in-use stock has grown in the past 20 years to around 220 000 tonnes in 2014. The 10th and 90th percentiles, resulting from the Monte Carlo simulation, account for ±12% or a range of roughly 55 000 tonnes (Figure 2a).

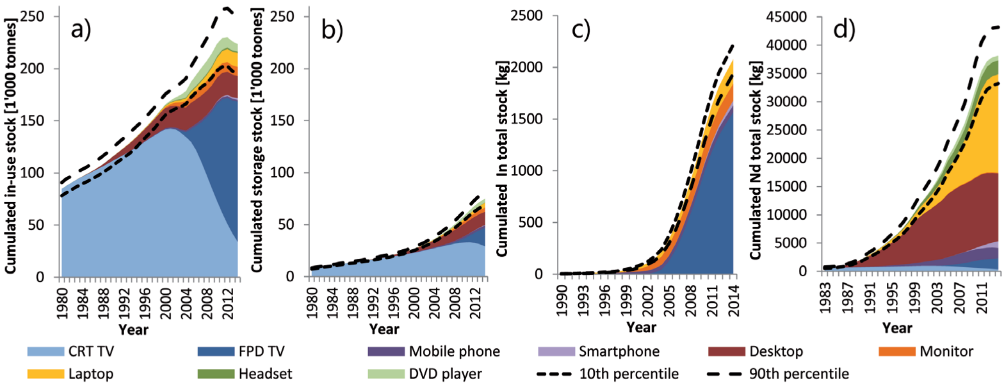

Figure 2: Cumulated a) in-use stock, b) storage stock, c) indium total stock, d) neodymium total stock (Thiébaud et al. 2016).

The storage stock comprises 75 000 ±9% tonnes in 2014 (Figure 2b). This accounts for 25% of the total stock. Both in-use stock and storage stock are dominated by CRT as well as FPD TVs and desktop computers. Although small devices such as mobile phones, smartphones and headsets are more abundant in the stock, by weight, they are insignificant. The in-use stock of CRT TVs and conventional mobile phones is declining as these device types are replaced by FPD TVs and smartphones, respectively. With the exception of smartphones, the in-use stocks of most device types are slowly approaching or have already reached saturation. Both replacement and saturation lead to a decreasing total in-use stock.

Reuse and storage significantly extend the total time a device remains in the use phase. Compared to the median service lifetime of new devices, the median total lifetime increases by 22% for CRT TVs, 80% for laptops and 130% for mobile phones (Thiébaud et al. 2016).

Electronic devices in Switzerland represent an In stock of over 2000 ±7% kg and a Nd stock of 38 000 ±13% kg (Figure 2c and 2d). Most of the In is stocked in FPD TVs, most Nd is found in desktop and laptop computers. With the change from Nd magnets containing hard disk drives (HDDs) to Nd free solid state drives (SSDs), the Nd stock will decrease in the future. An example of the simulated stocks and flows to, from and within the cascade model is depicted in Figure 3 for Nd in 2014 in the form of a Sankey Diagram. For the sake of clarity, we refrain from including uncertainty ranges. The share of the total storage stock on the total stock accounts for 30% for Nd and 15% for In. Most Nd-containing devices are stored after their first use, before they reach the collection scheme. The flows of In-containing devices to collection, storage and reuse after their first use are all of a similar order of magnitude. The small in-use stock 3 and storage stock 3 indicate that further uses occur, but are irrelevant. Overall, 3400 kg of Nd and 160 kg of In left the use phase in 2014, with the share of collected material accounting for 80% and 65%, respectively.

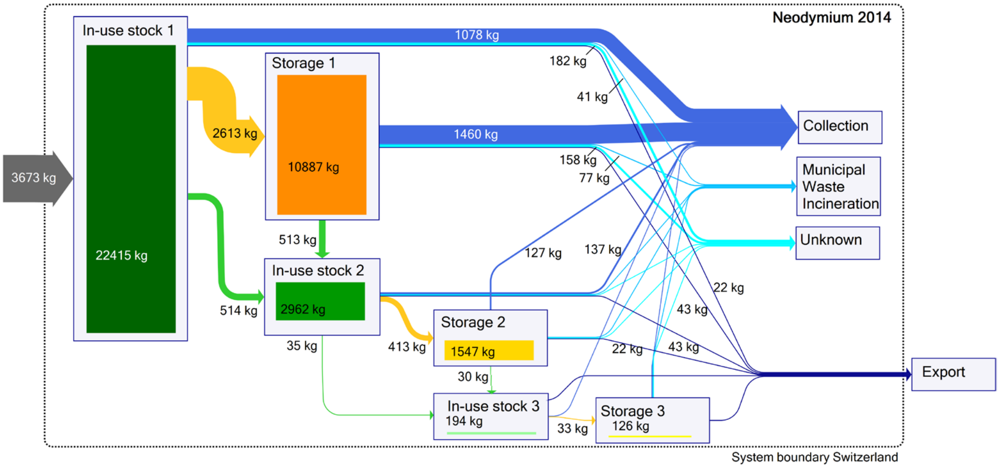

Figure 3: Nd flows in kg in 2014. Flows <20kg are not labeled.

The theoretical value of the collected material accounts for around 40 000 Euro and 170 000 Euro for In and Nd, respectively. As a comparison, the collected gold has a value of around 12 000 000 Euro. To date, the small quantities combined with low prices do not encourage Swiss recyclers to adapt their preprocessing and find appropriate downstream processes to recover In and Nd. Due to the delayed response of the system the outflows are still growing. As the transition from HDDs to SSDs has started around 2010 in Switzerland, a first decline of Nd in the outflows is expected to start around 2017. However, due to storage and reuse, Nd will still be found in the outflow for the next 20 years.

4 Conclusion and outlook

Our results provide new and important insights on product lifetimes and the transfer of devices and materials between active use, storage and disposal. We show that not only the service lifetime, but also the storage time and the internal flows between the in-use stock and the resulting storage stock are important variables to consider in dynamic MFAs. Our model thus gives insights into the “black box” in-use stock and is a first step towards a better understanding of the current stocks and flows of electronic equipment and critical raw materials.

At least 20% of In and Nd in Switzerland are lost due to incineration, export or unknown disposal pathways. The remaining quantities reaching the collection and recycling system are so low, that they are lost in the recycling and recovery processes. In a next step, the waste management system will be included in our model in order to trace the pathways and losses of critical raw materials in the entire system.

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