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The Austrian silver cycle: A material flow analysis

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ABSTRACT

Silver (Ag) is a precious metal of increasing importance. Besides its classical use as a valuable, it is applied in an increasing number of industrial products due to its advantageous chemical properties. As silver is considered a non-renewable resource, it is becoming more and more relevant for individual countries to gain a better understanding of their domestic silver material flows. In our study, a material flow analysis (MFA) of silver in Austria for the period 2012 was carried out, the results of which reveal the major silver flows in the country as well as the imports and exports outside the country. As there is no extraction of silver ore in Austria, the country is depending on silver imports and recycling. Furthermore, the role of the silver coin production that is of considerable importance in Austria is highlighted. The results may help, on a policy level, to determine silver use indicators and support the development of strategies for resource, waste and environmental management of silver. On a modeling level, the results may function as an example for future silver MFA studies in different countries.

1. Introduction

Silver (Ag) is a precious metal with increasing importance for today's society. Besides its usage in classical applications like jewellery, investments and coins, it is increasingly used in electrical and electronic products as well as cosmetics or medicines due to its special properties, namely its high electrical and thermal conductivity and its antibacterial effect (Atiyeh et al., 2007; Hammond, 2000; Silver, 2003; Newman et al., 2012; USGS, 2013; Goonan, 2014). Because of its advantageous properties and its application in new technologies, its importance is increasing and a clear understanding of silver stocks, flows and future trends is necessary (Goonan, 2014). Recent studies examined silver material use from a national point of view. For instance, Goonan (2014) focuses on the flows of silver into various end uses in the United States. Chen and Graedel (2012) review anthropogenic cycles of the elements and focus on national resource balances.

Silver is considered a non-renewable resource: in a research conducted on behalf of the German Federal Ministry of Economics and Technology, Frondel et al. (2005) calculated that the maximum estimated range of silver accounts would last merely 29years after using the *resource base-to-production ratio*. Kesler (2007 cited from Kesler 1994) determined that silver, basing its prognosis also on static assumption, would be available during 10–25 years. According to Kesler's prognosis, mankind would either have already run out of silver or would very soon do so. This is, however, not the case. Prognoses based on *resource base-to-production ratio* are overly pessimistic (Simon, 1998) as they, for example, exclude the discovery and exploitation of new silver mines and the recycling of silver scrap. Giving a reasonable estimate of how long a resource might last is highly problematic; this involves not only its geological availability, which cannot be clearly determined, but also includes other factors of a technical, environmental, social, political, and economic nature (NRC, 2008). Yet, the *resource base-to-production ratio* can be seen as a kind of indicator or at least as a (temporary) warning signal showing a potential future possible shortage. A recent study by Nassar et al. (2012), where the degree of criticality of the metals of the geological copper family (Cu, As, Se, Ag, Te, and Au) has been quantified, shows that the supply risk over the medium and long term for silver is high. In general there are various assessments regarding the availability of metals over the long run which show differing results (see for instance NRC, 2008; Pfleger et al., 2009), varying from not critical to insecure for silver (see for instance European Commission, 2010; Morley and Eatherley, 2008). This is due to the sparse availability of information as well as the different aims of the assessments (Nassar et al., 2012). As silver is a non-renewable resource and its role in modern electronics is gaining importance (Nassar et al., 2012) there might thus be not enough silver for new and existing applications and therefore alternative

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materials must be found in the near future. In order to achieve a better understanding of silver supply and demand on which basis strategies can be developed, the above ground stocks and the corresponding flows might be of interest.

Material flow analysis (MFA) is a method that allows, through quantification of stocks and flows, to get an advanced understanding of material ground stocks (Johnson et al., 2005b; Bringezu and Moriguchi, 2002). To date, there are already numerous MFA studies on technologically significant metals – such as copper (Graedel et al., 2004) or zinc (Graedel et al., 2005) – that have primarily been performed within the *Stocks and Flows Project* initiated by the Centre for Industrial Ecology at Yale University (Eckelman and Graedel, 2007; Harper et al., 2006).

There are some MFA-studies for silver as well. One of these studies is on a worldwide scale, whereas the other four studies are carried out at a regional level. (1) Johnson et al. (2005b) examined 64 countries or country groups that include more than 90% of all worldwide silver flows for the year 1997. Austria was also among these 64 countries, which were analyzed in this study. (2) In turn, Henderson (2003) surveyed the silver flows for Commonwealth of Independent States (CIS) countries for 1998, while (3) Lanzano et al. (2006) considered the silver cycle for Europe implying the most relevant 19 countries for 1997. (4) Johnson et al. (2005a) also examined the Asian silver cycle in 1997 for 11 countries. (5) Furthermore, Goonan (2014) surveyed the silver flows in the United States for 2009. In almost all of these studies, data availability and reliability is a crucial topic, and almost all of them face basically the same problem, as Johnson et al. (2005a) put it: "*The reliability and availability of the data varied, with the most confidence given to earlier life stages and the most uncertainty existing later*" (p. 93). Henderson (2003) even asserted that in the later life stage data from other countries "*WM [waste management] data for CIS countries were unavailable in many cases, so estimations based on European statistics were often employed*." The main reason for this is that data comes from institutional reports, such as the *World Silver Survey* by The Silver Institute, which is more concerned with providing data on mining, manufacturing and re-use of scrap than with providing data about non-reusable scrap flows.

The study by Goonan (2014) examines the lifecycle of silver in the USA. Hence, it is the only study on a country level to date. However, this study used a rather complex framework and the processes are not grouped as in the framework developed within the *Stocks and Flows Project.* Furthermore the data sources and the quality of the used data are not fully clear. All of the other studies presented are not carried out on a country level but rather on a regional level. These studies came to their results by taking data from either individual countries or from a smaller group of countries and grouped these in order to build a MFA model on a bigger scale. However, the studies performed on a country level are rather rough as regards model structure and data employed. Using a simple model structure that focuses only on some main flows is sufficient for a world or a large regional study, as it makes the models comparable and an overly detailed view is not necessary. The same accounts for the data: it would be an unreasonable workload and probably hardly possible to gather the same detailed data for 64 countries, when its main aim is to get a basic understanding of the most important stocks and flows. Nevertheless, it is of crucial interest for individual countries to get a more detailed picture of its silver flows and, to our knowledge, there is so far no comprehensive study on silver for a single country. Furthermore, the studies are somewhat outdated as they mostly use data from 1997: the price of silver has increased sharply since then, and applications as well as the recycling of silver have also changed. Therefore, our main objective is to build a comprehensive MFA-silver study for a country with base year 2012.

In our MFA study we aim at determining the flow patterns of silver for Austria in 2012. We choose Austria, as it provided us with the most convenient example in terms of data gathering. Our key research question can be formulated as: *What are the most relevant stocks and flows of silver, in terms of magnitude as well as economic and social importance, in Austria for the year 2012?* The results obtained by answering this question can work both at a modeling and at a policy level: at a modeling level, the results show how to carry out a MFA study for silver for a single country. On a policy level, the results can be used by people interested in silver and Austrian policy makers to get an overview of the Austrian silver cycle for 2012, together with revealing crucial aspects such as the amount of recovered silver waste, the amount of lost waste and the amount of imports and exports of silver.

The article is divided into five sections: after this introduction, Section 2 briefly introduces the method of MFA. The results of the MFA are represented in Section 3 and discussed in Section 4. Section 5 presents our conclusions.

2. Methodology

Material flow analysis (MFA) is a systematic approach to assess the flows and stocks of a substance or material in a system, which is clearly defined in space and time (Brunner and Rechberger, 2004). The possibility to develop such a model for a big variety of substances or materials, along with its clear structure, usefulness and simplification make it a widely applied policy decision support tool in a variety of fields including resource management, environmental management, process control, waste treatment, etc. (Huang et al., 2012). The assessment of environmental and anthropogenic processes requires systematic and comprehensive data: this data, acquired by analysis of socioeconomic, industrial and environmental systems, can be the basis for consistent models of material flows. One obstacle for such comprehensive databases, tough, is the lack of coordination for systematically tracking and monitoring material and substance flows (Kovanda et al., 2012). Today, frameworks for a standardized reporting of material and substance flows have been established; in this study, the systematic evaluation of silver use in Austria is based on the generic MFA framework which was developed and applied within the *Stocks and Flows Project* (Chen and Graedel, 2012; Eckelman and Graedel, 2007; Harper et al., 2006; Lanzano et al., 2006). The framework consists of a total of four main processes, each of which can be subdivided into various sub-processes. The four main processes in our system were:

(1) *The production process*: Crude silver ore is extracted, separated from its parent materials, and processed into refined silver.
(2) *The fabrication and manufacture process*: Silver semi-products are produced from refined silver. The silver semi-products are then used in the manufacture process to make the finished silver products. Scrap is sent back to fabrication or to the production process for recycling.
(3) *The use process*: In this process, silver is available either in the form of finished silver and silver alloy products or in the form of components of finished products.
(4) *The waste management process*: The associated waste streams within this process are municipal solid waste, waste from electrical and electronic equipment, industrial waste, and hazardous waste. The discarded silver is recycled back into refined silver, treated thermally in an incineration plant or stored in landfills.

The separate consideration of these four processes allows for a standardized representation of data and thus increases the comparability with other studies. Nevertheless, a detailed analysis of stocks and flows can be performed within this framework, while the respective substance flows can be grouped in the four main