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Substance flow analysis of lithium for sustainable management in mainland China: 2007–2014

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ABSTRACT

Lithium as an energy metal has gained significance in a wide range of application that spread across many industry sectors, along with its key role in emerging electric vehicles. China is a key use and producer of lithium and related products. In order to draw an entire picture of the lithium cycle, this study attempts to quantify the flows, stocks, and loss of lithium in the anthropogenic cycle in China, from 2007 to 2014. Substance Flow Analysis is employed in this paper for data mining and compilation. The results illustrate that production and use increased greatly from 2007 to 2014, due to the fast increase of the lithium ion battery. China's lithium industry still heavily relied on the import of natural lithium ores, where lithium exports were mainly in the form of lithium ion battery-powered products, including laptop computers, mobile phones and electric bicycles. The stocks of lithium increased gradually from 2007 to 2014, but the loss of lithium from direct use also increased and more quickly. Therefore, the lithium stock in society cannot provide meaningful quantities as the second source for lithium production. It is suggested that the lithium in batteries should be recovered, as most lithium inputs are dispersed back into the environment, while the lithium industry still relies on imported lithium resources in China.

1. Introduction

In recent years, Battery Electric Vehicles (BEVs) have gained in popularity in China, playing a key role in strategies that support energy conservation and emission reduction. BEVs are expected to contribute greatly to a reduction in the use of fossil fuels use and Greenhouse Gas (GHGs) emissions, as there will be more and more electricity generated by renewable or clean energy sources. Along with the rapid development of BEVs, lithium, as the indispensable element in the power battery, is becoming more and more vital due to its unique characteristics in energy storage.

Several studies stated that, lithium resources were sufficient to meet the long-term, global demands of the BEV batteries and existing lithium-use industries until 2100 (Gruber et al., 2011). However, these studies also showed that lithium is a geographically scarce metal (Grosjean et al., 2012; Miedema and Moll, 2013); for example, 77.6% of global lithium resources were mined in Chile, Australia and Argentina in 2013 (USGS, 2015). In the EU, it has been proved that lithium will be a bottleneck (especially for the BEVs) for EU27 in the future (Miedema and Moll, 2013).

As China is one of world's major lithium use countries, it is necessary to identify lithium stocks and flows in the economic and industrial system. The macro picture can help improve existing policies on highly efficient utilization and the potential lithium cycle. The lithium resource reserve in China is about 13.67% of the world (USGS, 2015), but the mining capacity is still under construction. Moreover, China is one of the largest Lithium Ion Battery (LIB) manufacturing countries in the world, so there are still a large quantity of lithium ores and brines imported to China.

Similar to the EU situation, the natural lithium resource reserve in China, added with even 100% recovered lithium from waste LIBs, still cannot fulfill the demands of lithium ion batteries in the long term until 2100 (Zeng and Li, 2013). However, due to more exploration for lithium in China, the lithium reserve increased to 3.5 million tons in 2014 (USGS, 2015), which may result in a different conclusion of the lithium supply in China. Moreover, the import and export of lithium and lithium-containing products make the situation more complicated. A large portion of lithium-containing products are exported from China, while lithium ores and lithium compounds are imported in recent years. Therefore, it is necessary to identify the actual lithium flows and stocks in greater detail in order to arrive at a complete picture of sustainable management of lithium in China.

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Substance Flow Analysis (SFA) is used in this study for dynamic analysis of lithium stocks and flows in China from 2007 to 2014. The aim of this paper is to quantify the amount of lithium that entered, left, and accumulated in China's anthroposphere, in order to see how the electric vehicle industry affected the flows and stocks of lithium until now. Lithium flows between the economic system and the environmental system, and the lithium stocks inside the economic system, were studied.

The paper is organized as follows: Section 2 defines the methodology, scope and system boundaries; Section 3 shows the major data sources and specific analysis settings; Section 4 shows and analyzes results of flows and stocks; in the last two sections, the main conclusion and the next step for improvement are discussed.

2. Methodology and scope definition

2.1. Substance flow analysis

SFA is a systematic analysis tool in the field of industrial ecology. With this method, the substance flows and stocks between the socioeconomic system and the environment, or within the socioeconomic system, in the specific region in a defined time range were identified and quantified (Lindqvist and von Malmborg, 2004). The results of SFA could produce the big picture for sustainable management of essential resources, solid waste, and hazardous materials management policies in cities (Lindqvist and von Malmborg, 2004), countries (Guo and Song, 2008), and even the whole world (Spatari et al., 2005). Especially for metals, SFA can provide insights into quantifying recovery efficiencies of metals at the end-of-life (EOL) stage, international trade estimation of metals embedded in all kinds of products, and assessment on emissions or loss of metals back into natural environments (Chen and Graedel, 2012).

Existing SFA studies can be divided into two categories: static SFA and dynamic SFA, which differ from each other by their range of time. The static SFA category focuses on the snapshot in a short period (such as one year) as a time point, while the dynamic SFA can deal with flow changes and accumulated stocks in society over successive, several or even scores of years (Lu, 2000; Chen and Shi, 2012). Employing dynamic SFA, stocks from different reservoirs can be identified to provide information on which stocks and flows to address in the future for secondary recovery efforts (Spatari et al., 2005; Park et al., 2011).

This study analyzes the lithium flows and stocks in a dynamic sense, in order to identify the types of reservoirs richest in lithium. There are different ways to implement the dynamic SFA the literature, including a population balance model (Yokota et al., 2003; Hatayama et al., 2007), top-down approach (Müller et al., 2006) or delay model (Kleijn et al., 2000). Until now, no method has yet been officially standardized for performing dynamic MFA (Spatari et al., 2005). Through analysis of existing dynamic SFA studies, the general steps of dynamic SFA include scope definition, identification of stocks and flows, lifetime estimation of material containing products for quantification of stocks and the interpretation of SFA results (Brunner and Rechberger, 2004; Lindqvist and von Malmborg, 2004). In this study, the general steps of dynamic SFA above were followed.

2.2. Scope and system boundary

The target system of SFA was defined by spatial and temporal boundaries. The geography scope was set as mainland China, while the time range was from 2007 to 2014. The reason for this time scope is that BEVs began to develop at a large scale in China in 2007; i.e., the annual output was from less than 800 in 2007 to more than 45 thousand in 2014, which may greatly affect the use of lithium (Anon, 2014).

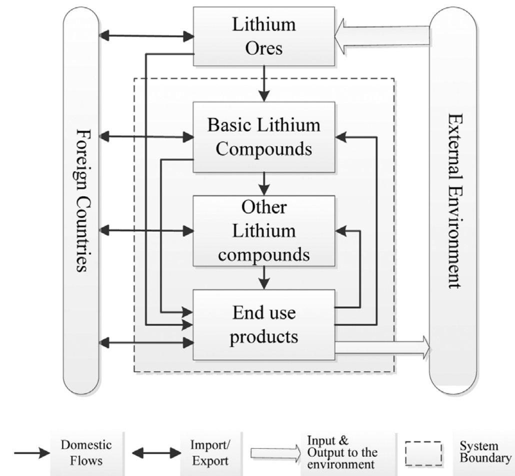

Fig. 1. Scope of lithium flows and stocks analysis in China.

In this paper, continuous mass balance analysis was used to calculate the quantity of lithium from ore to basic compounds, from basic compounds to high level compounds, from compounds to products for end-use (including battery powered products), and from there into waste deposits or recycling. In other words, all the life cycle stages of lithium were covered, including ores mining, extraction, compounds manufacturing, used, stocked, disposed, and key lithium products imported and exported from China. With time-series input data, the changes of lithium stocks over multiple years were analyzed. From the life cycle point of view, these stages were included: mining of lithium ores, lithium product manufacturing, use and waste treatment, shown in Fig. 1. Each life-cycle stage contained subcategories, such as production of lithium carbonate, lithium hydroxide, and lithium chloride in the production stage of basic compounds.

The nature reserve and flows, and the stocks and flows in society can both be investigated in SFA, generally. However, according to the aim of this study, only lithium in the anthropogenic cycle was investigated.

3. Accounting method and data preparation

The accounting method in this section mainly refers to how the flows and stocks were calculated. According to the mass conservation law, the total input for each process and system should be equal to the output. There are four detailed ways for calculating flows and stocks of substance in this study: (1) calculated directly from the statistics, such as import and export flows; (2) calculated by combining statistics with coefficients, such as use flows for battery-powered products; (3) deduced by mass balance (Chen and Graedel, 2012); and (4) modeled by the existing WEEE generation estimation methods, such as lithium stock estimation (Wang et al., 2013; Li et al., 2015). In this study, the calculation methods of all flows and stocks followed one of the above calculation methods.

Most of the lithium existed in the form of compounds in the anthropogenic system, except lithium metal in the Al-Li alloys and ores for glass and ceramics. Therefore, it is worth mentioning that the stocks and flows values in this study mostly mean the quantity of lithium element, for all lithium containing ores, brines, compounds and the final products.

For calculation of lithium flows, it is necessary to identify the key flows of lithium in the production and use processes in China. Based on the literature investigation, the main production and use