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Tracing global lithium flow: A trade-linked material flow analysis

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ABSTRACT

Lithium is an indispensable ingredient for the next-generation clean technologies. With the aim of identifying opportunities to improve lithium resource efficiency, this study establishes a trade-linked material flow analysis framework to analyze the lithium flow both along its life cycle on the national level and international trade on the global level. The results indicate that global lithium production reached 171 kt lithium carbonate equivalent in 2014. Chile, Australia and China played the leading roles in lithium commodity production. 75% of lithium-ion batteries are used for consumer electronics. From the international trade perspective, the trade of lithium commodities existed commonly all around the world. The major origins of lithium minerals and chemicals were Chile, Australia and Argentina. China was the major destination of lithium minerals and chemicals. Lithium carbonate, ores, and lithium concentrate were the three dominating trade commodities, altogether accounting for 67% of total trade volume. This study implies high necessity of establishing domestic lithium recycling system and international cooperation between trade partners in lithium waste management.

1. Introduction

Lithium is conventionally used as an industrial ingredient for the productions of lubricating greases, glasses, ceramics, etc. Historically, these uses kept 40%–50% share of global lithium consumption (USGS, 2014). Starting from almost a decade ago, lithium consumption experienced a major surge with the market expansion of consumer electronics, which have large demand for lithium-ion batteries. The share of lithium used in rechargeable batteries expanded from 23% in 2008 to 35% in 2014 (USGS, 2016). Over recent years, lithium found intensive applications in emerging clean technologies, especially as the cathode material of electric vehicle (EV) batteries.

Accordingly, global lithium consumption experienced rapid growth (USGS, 2014). As Fig. 1 shows, global lithium consumption increased from 79 kt lithium carbonate equivalent (LCE) in 2004 to 165 kt LCE in 2014, implying an annual growth rate of 8%. In 2014, the shares of lithium consumption for various uses were: batteries, 35%; ceramics and glasses, 32%; lubricating greases, 9%; and other uses, 24%. The fast growth of lithium consumption imposed significant pressure on the supply side, which raises global concern on lithium resource security and utilization efficiency.

Under such a circumstance, intensive studies have been conducted to investigate the flow characteristics of lithium. Existing studies can be generally divided into three categories. First, tracing lithium flow through its whole life cycle, including resource mining, chemical production, product manufacture, product use, and waste management. Such studies were conducted on either the global level or national level. Ziemann et al. (2012) established a global lithium flow model containing production, manufacture and use for the year 2007. The results showed that there was a 4130 ton discrepancy between lithium production and consumption. Hao et al. (2017) analyzed lithium flow for the world's largest lithium consumer, China, in 2015. Their study revealed that the growth of EV market would possibly increase China's dependence on lithium import, which aroused the supply security concerns.

Second, investigating the situation of lithium supply and demand. Zeng and Li (2013) studied the lithium reserves and demand in China, finding that with the rapid increase of lithium use, the lithium recycling rate need to be at least 90% to realize the supply-demand balance. Miedema and Moll (2013) investigated the lithium availability for EVs in the EU, expecting that the lithium supply will reach over 0.5 Mt in 2050.

Third, tracking material and energy flow for end-of-life lithium products. Chang et al. (2009) traced the lithium-ion battery (LIB) flow in Taiwan for the year 2006, revealing that a total of 2.8 kt LIBs were stocked in Taiwan with a recycle value of 39 million dollars. Mellino

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Abbreviations: BEB, Battery electric bus; BEPV, Battery electric passenger vehicle; CNMIA, China Nonferrous Metals Industry Association; EV, electric vehicles; LCE, lithium carbonate equivalent; LCO, lithium cobalt oxide; LFP, lithium iron phosphate; LIB, lithium-ion battery; LiPF, lithium hexafluorophosphate; LMO, lithium manganese oxide; MFA, material flow analysis; NCM, lithium nickel cobalt manganese oxide; PHEB, Plug-in hybrid electric bus; PHEPV, Plug-in hybrid electric passenger vehicle; USGS, United States Geological Survey

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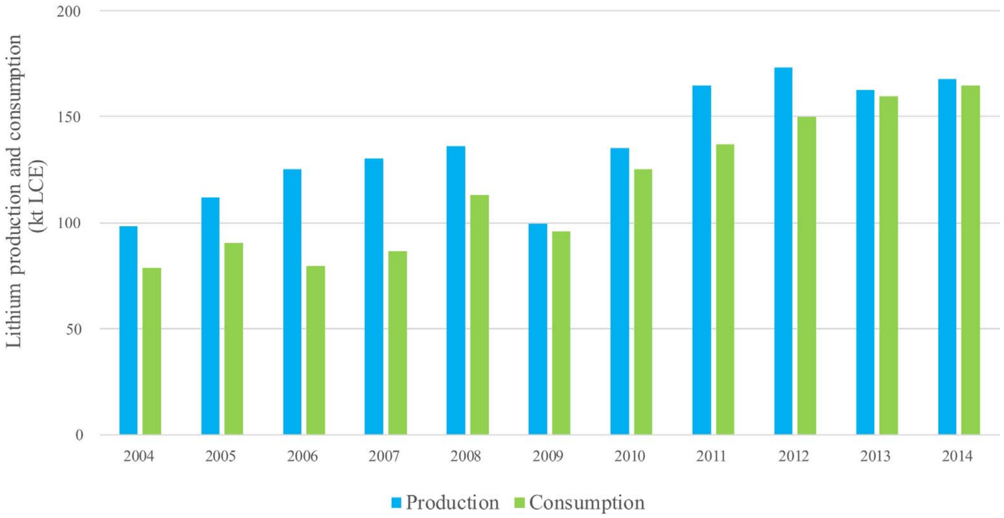

Fig. 1. Global lithium production and consumption.Note: Data from USGS (2016).

et al. (2016) studied the environmental impacts of lithium battery powered EVs in their life cycle, finding that the EVs generally have better environmental impacts than internal combustion engine vehicles. Richa et al. (2014) studied the LIB waste flows from EVs, finding that only 42% of the metal materials can be recycled in the U.S.

Above all, existing studies have laid a solid foundation for analyzing lithium flow on multiple spatial and temporal scales. However, few studies combined national lithium flow with international lithium trade, which is an important basis for analyzing lithium resource efficiency on both the global and regional scales. In order to fill such a gap, by establishing a trade-linked material flow analysis (MFA) framework, this study quantitatively traces the lithium flow both along its life cycle in specific countries and international trade among these countries (Liu and Muller, 2013). This study aims to answer what the lithium conversion pathways are on the national level; and what the origins, pathways and destinations of global lithium journeys are. This study contributes to theoretically establishing a trade-linked MFA model of lithium; and empirically mapping the international connections of national lithium material cycles. The whole paper is organized as follows. The next section explains the system boundary, key processes, methods and data. Following that, the results are presented. The final section concludes the whole study.

2. Methods and data

2.1. System boundary

The system boundary in this study is characterized by spatial boundary and temporal boundary. Regarding the spatial boundary, lithium production and consumption mostly occur in a few key countries. For this reason, the countries in Group of Twenty (G20), representing 85% of global economy output and 72% of international trade (UN Comtrade, 2016), are chosen to be analyzed. Besides, Chile is also covered in the analysis considering its key role in lithium brine mining, which supported 36% global lithium resource mining in 2014 (USGS, 2014). The selected countries and their respective international trade proportions are shown in Table 1. Regarding the temporal boundary, as the global EV market experienced a significant surge in 2014, which had a critical impact on global lithium flow, this study chose 2014 as the target year. More recent years are not analyzed due to data availability.

2.2. Key processes

The major processes throughout the lithium life cycle are shown in Fig. 2. These processes can be divided into five stages: resource mining, chemical production, product manufacture, product use and waste management. At the resource mining stage, there are three kinds of lithium resources, ore, brine and clay (Sverdrup, 2016). Lithium ore with 1%–4% lithium oxide is mined from the deposit and then processed into lithium chemicals. The main three types of lithium ores are spodumene, lepidolithe and petalite, which differ in lithium oxide content. Brine is mainly extracted from the subsurface salt lakes and then concentrated to produce various lithium chemicals. Brine can also be extracted from oil filed and deep sea, although not in large scale. The mining cost of brines is lower compared to ores, which makes brine the major source of lithium. Clay is generally extracted from lithium-containing rock and then processed into lithium chemicals. As the utilization of clays is currently quite limited, they are not covered in the analysis (Cai and Li, 2017).

Table 1
Selected countries and their international trade proportions.

Country	Code	International trade proportion
European Union	EU	15.51%
China	CHN	14.43%
the United States of America	USA	13.53%
Japan	JPN	5.04%
South Korea	KOR	3.69%
Canada	CAN	3.14%
Mexico	MEX	2.67%
Russia	RUS	2.63%
India	IND	2.61%
Saudi Arabia	SAU	1.71%
Australia	AUS	1.57%
Brazil	BRA	1.52%
Turkey	TUR	1.34%
Indonesia	IDN	1.19%
South Africa	ZAF	0.64%
Chile	CHL	0.50%
Argentina	ARG	0.45%
Total		72.17%

In the chemical production stage, the lithium minerals are firstly converted to basic chemicals including lithium carbonate, lithium hydroxide, and lithium chloride (Tianqi, 2015). These basic chemicals are then used to produce many derivatives. Using lithium carbonate as an example, it is mainly used to produce LIB cathode materials including lithium cobalt oxide (LCO), lithium manganese oxide (LMO), lithium iron phosphate (LFP), lithium nickel cobalt manganese oxide (NCM), etc.

In the product manufacture stage, lithium chemicals are used to