Resources Policy 51 (2017) 100–106

Contents lists available at ScienceDirect

Resources Policy

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

Material flow analysis of lithium in China

Han Hao[a], Zongwei Liu[a], Fuquan Zhao[a,*], Yong Geng[b,*], Joseph Sarkis[c]

[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] School of Environmental Science and Engineering, Shanghai Jiaotong University, Shanghai 200240, China
[c] Worcester Polytechnic Institute, Worchester, MA 01609-2280, USA

A R T I C L E I N F O

Keywords:
Lithium
China
Material flow analysis
Lithium-ion battery
Electric vehicle

A B S T R A C T

Lithium has an increasingly strategic role as clean technologies emerge. This strategic role is especially evident for electric vehicle technology with a critical dependence on lithium-ion battery technology. China is the world's largest lithium consumer due to its rapid economic development, large population, and soaring consumer demand for electric vehicles driven by stricter air quality control regulations. Given this background, this study introduces the first lithium material flow analysis (MFA) for China. This MFA will inform national lithium management plans. The MFA results indicate that China's consumption was 86.7 kt of lithium carbonate equivalent in 2015, accounting for 50% of the global total. China's lithium resource is highly dependent on imports, 70% of spodumene concentrate is imported from Australia alone. Along the material life cycle (value) chain, lithium outflows were primarily from exports of lithium chemicals and lithium-embodied products. Remaining lithium in-use stocks are embodied in electric vehicles, consumer electronics, lubricating greases, and glasses/ceramics. Electric vehicle sales growth projections will likely increase China's dependence on lithium imports, lead to potential lithium supply security concerns for China. Large amount of lithium stock embodied in electric vehicles and other lithium-ion battery-containing products implies more opportunities for lithium recycling in a circular economy context.

1. Introduction

Lithium, the lightest metallic element, is a relatively rare element on earth (Garrett, 2004). Lithium naturally occurs in compound forms because of its high reactivity. Lithium is found with very low concentrations in natural brines and pegmatites. These compounds include spodumene, lepidolite, and petalite. The global lithium reserve is estimated at 14.0 megatons (Jaskula, 2016), which is 74.5 megatons of lithium carbonate equivalent (LCE). Lithium reserves are mainly distributed in South America, Australia, and China (see Fig. 1).

Commercially, lithium is used to produce various chemicals, most of which are indispensable to modern industry. As an ingredient it has been used in various materials such as lubricating greases, glasses, and ceramics. Lithium has also seen application in critical energy storage products such as lithium-ion batteries. These batteries are essential components in consumer electronics, energy storage systems, and electric vehicles. In 2015 global lithium resource mining reached 0.17 megatons LCE (Jaskula, 2016). Lithium mining increased by 58% over the past decade because of growing and multiple industrial uses. It is expected that increasing global demand for electric vehicles will mean that global lithium consumption will also experience substantially greater demands over the next few decades (Hao et al., 2016). Consequently, understanding the potential impact of lithium supply, consumption and flows is critical for social and economic development during this time period (Dunn et al., 2012; Kang et al., 2013; Li et al., 2014; Majeau-Bettez et al., 2011) (Fig. 2).

China is the largest lithium consumer in the world. China has a relatively rich lithium reserve of 17.0 megatons of LCE accounting for 23% of global reserves. However, China's lithium reserve grade is relatively low resulting in high lithium resource mining costs (Zeng and Li, 2013). Thus, China's lithium demand is primarily met through foreign imports. In 2015, while China's share of global lithium production was 7%, its global share of consumption was 50% (Jaskula, 2016). China's domestic consumption was mainly met through spodumene concentrate imports from Australia.

Stricter air quality control policies in China have fueled electric vehicle demand growth. Electric vehicle production in China in 2015 reached 379,000 vehicles, a 400% increase from the previous year. This level of electric vehicle production has made China the world's largest electric vehicle producer. This electric vehicle production growth also increased the demand and market price of lithium carbonate from 43,000 Yuan/t in early 2015 to 129,000 Yuan/t in late 2015 (Zhang,

* Corresponding authors.
E-mail addresses: zhaofuquan@tsinghua.edu.cn (F. Zhao), ygeng@sjtu.edu.cn (Y. Geng).

http://dx.doi.org/10.1016/j.resourpol.2016.12.005
Received 6 November 2016; Received in revised form 3 December 2016; Accepted 5 December 2016
0301-4207/

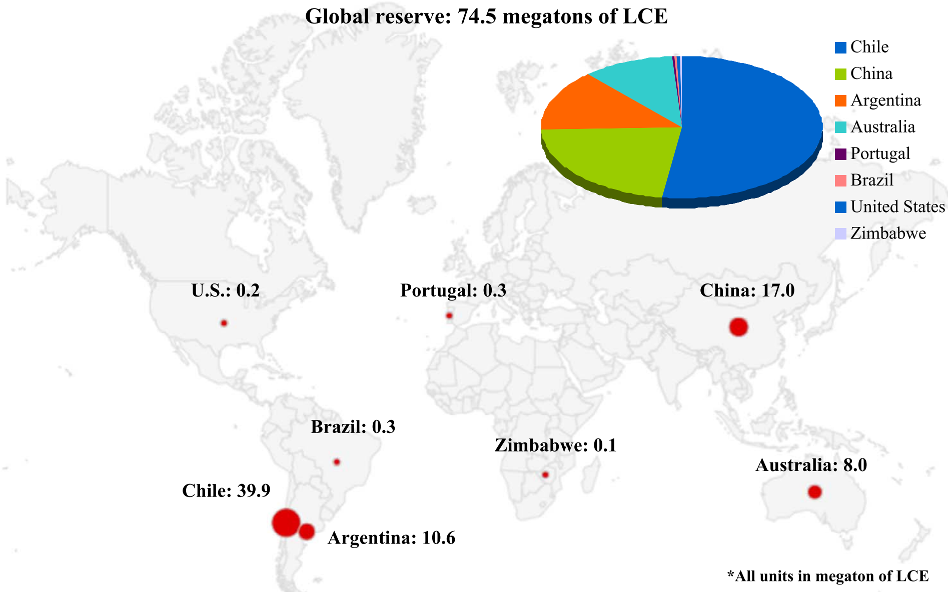

Fig. 1. Global distribution of lithium reserves.

2016). Thus, manufacturers have become concerned on how to maintain a sustainable supply of lithium compounds.

A material flow analysis (MFA) can help policy makers, researchers, and industry gain insights on addressing lithium scarcity concerns. Ziemann et al. developed the first global lithium flow model and found a noticeable discrepancy between production and consumption (Ziemann et al., 2012). Numerous studies investigated the global lithium supply-demand relationship in the context of corresponding lithium-ion battery demand (Habib and Wenzel, 2014; Pehlken et al., 2015; Speirs et al., 2014; Vikström et al., 2013; Chang et al., 2009). Global-level MFA studies have been conducted for many commodities such as aluminum (Liu and Müller, 2013) and copper (Gerst, 2009). However no peer reviewed publication has completed a lithium MFA within the Chinese context. This study seeks to fill this gap by developing a lithium flow chart for China. From this analysis we also identify major challenges and opportunities for lithium supply and identify how lithium resource efficiency can be improved.

The remainder of this paper begins by describing the MFA method. Section 3 presents the research results, including the lithium flow chart. Finally, Section 4 concludes the paper by identifying related policy issues.

2. Material flow analysis

MFA is a systemic assessment of the flows and stocks of materials defined in space and time (Brunner and Rechberger, 2004). This study is conducted by the following MFA steps: system definition, analysis of processes, schematic modeling and interpretation of results.

2.1. System boundary

The spatial boundary is mainland China (China for short). Taiwan, Hong Kong and Macau are excluded from the analysis. The analysis temporal boundary is the year 2015. The year 2015 is chosen to reflect lithium flow trends driven by electric vehicle market growth in China. Using lithium processing activities five basic stages along the life cycle chain are used in the analysis. These stages include resource mining, chemical production, product manufacture, product use and waste management. The inputs, outputs and stocks for each stage are calibrated using data from the Ministry of Industry and Information Technology MIIT (2016), General Administration of Customs GAC (2016), and the China Nonferrous Metals Industry Association CNMIA (2016). The details of data compilation and treatment are described in Supplementary Information (SI) documentation.

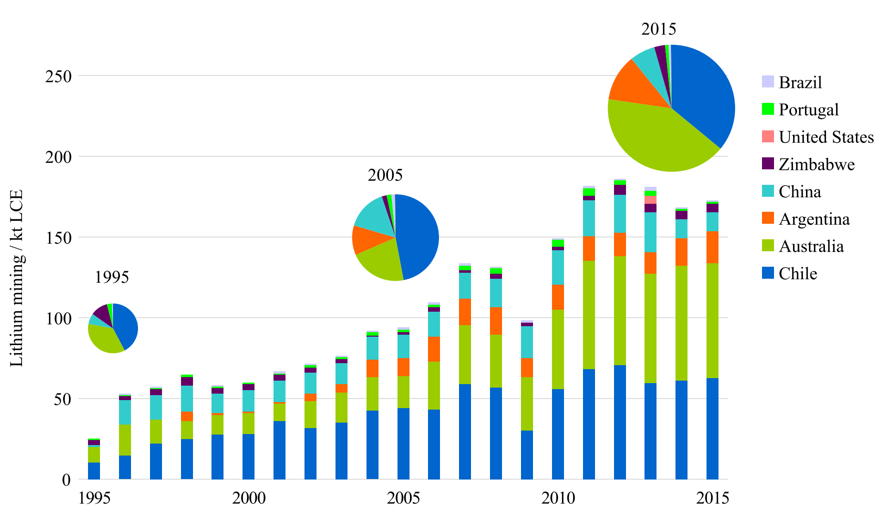

Fig. 2. Lithium mining in key countries.