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

Xin Sun, Han Hao*, Fuquan Zhao, Zongwei Liu

State Key Laboratory of Automotive Safety Energy, Tsinghua University, Beijing 100084, China

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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

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

* Corresponding author.
E-mail address: hao@tsinghua.edu.cn (H. Hao).

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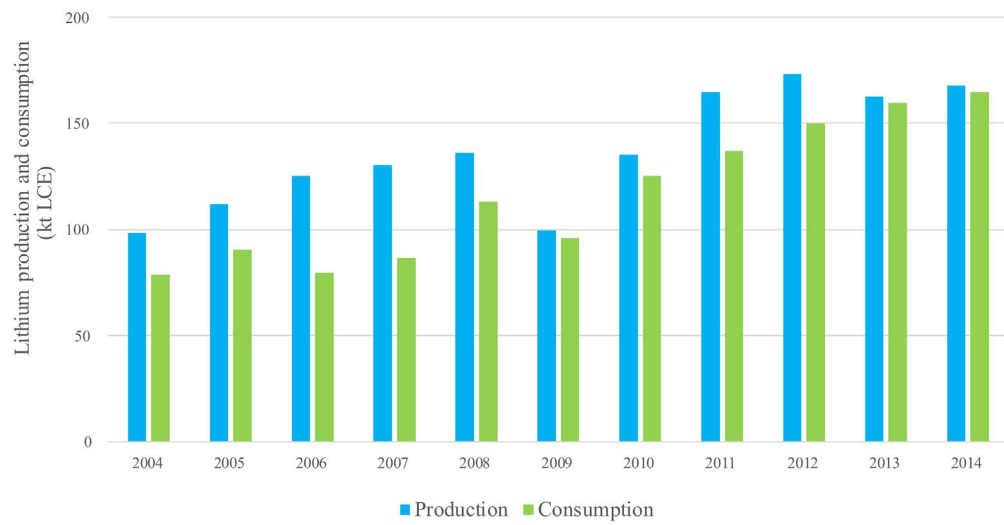

Fig. 1. Global lithium production and consumption.Note: Data from USGS (2016).

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).

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

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%

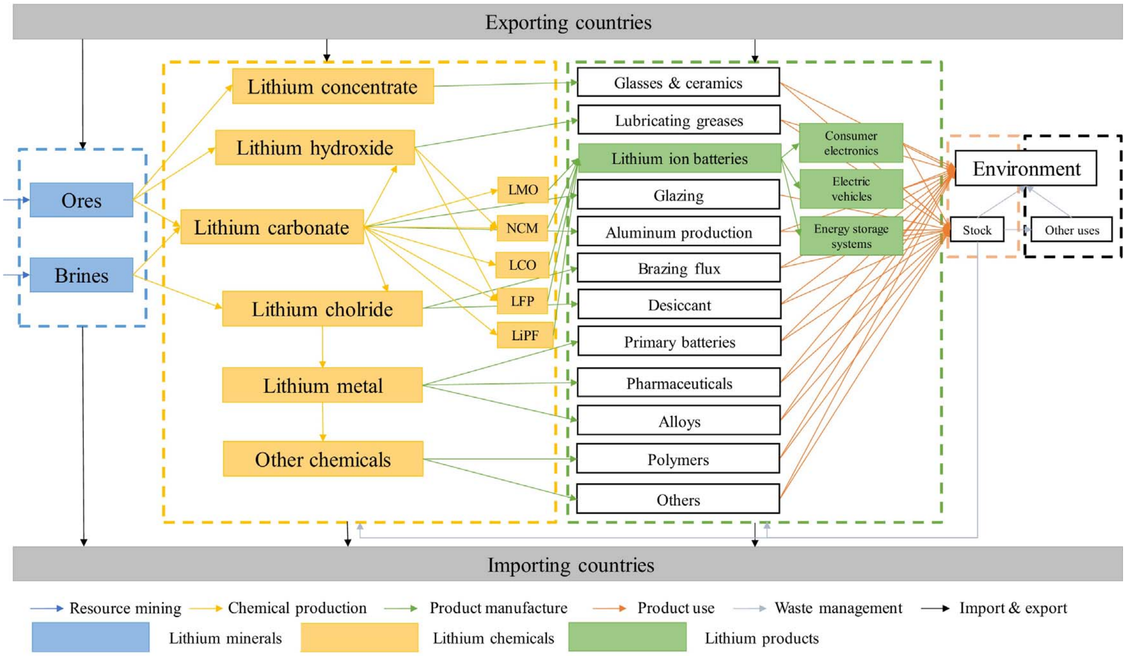

Fig. 2. Processes and flows throughout the lithium life cycle.Note: Only the lithium commodities represented by the colored blocks are covered in the analysis.

produce a wide range of products. Lithium concentrate is widely used in glasses and ceramics industries. Besides being used to produce cathode materials, Lithium carbonate is also used for glazing and primary aluminum production. Lithium hydroxide is the essential raw material for lithium-base lubricating greases which have good low temperature performance. Lithium chloride is required for brazing flux and desiccant. In addition to the applications above, lithium chemicals are also used in pharmaceuticals, alloys, polymers, etc (Hao et al., 2017). The products containing LIBs as power sources are also covered in this stage, including consumer electronics, EVs and energy storage systems. Consumer electronics can be further divided into mobile phones and portable computers. EVs can be further divided into Battery electric buses (BEB), Battery electric passenger vehicles (BEPV), Plug-in hybrid electric buses (PHBEB), and Plug-in hybrid electric passenger vehicles (PHEPV).

Considering the product manufacture stage, this study focuses on the productions of LIBs and their derivatives. These products represent the largest part of lithium consumption and global lithium-containing products flow (USGS, 2014). Besides, LIBs and their derivatives have higher potentials of lithium recycling compared to other lithium-containing products.

It is hard to trace the flow of in-use products and the waste stream inside and across the countries. For these flows, little reliable data can be obtained, which is not enough for a robust estimation. With this concern, the stages of product use and waste management are not covered in this study.

2.3. Method

MFA is the systematic analysis tool to trace the flows and stocks of material in a specific spatial and temporal frame. With the method, the material stocks and flows within the system boundary can be qualitatively and quantitatively studied. Further, the influences of the identified material flows can be observed. For this reason, the results of MFA are of high relevance and importance to the policy makers.

This study investigates each process along the lithium life cycle by defining five variables: production, import, export, consumption, and stock. The relationship among these five variables follows the law of conservation of mass, as Eq. (1) shows.

$$\triangle ST = PR + IM - EX - CO \quad (1)$$

Where,

$\triangle ST$ is the change of commodity stock (t LCE);
PR is the commodity production (t LCE);
IM is the commodity import (t LCE);
EX is the commodity export (t LCE);
CO is the commodity consumption (t LCE).

In order to facilitate the calculation, conversion coefficients are used to convert the unit of each variable to the unit of t LCE. The conversion coefficients are presented in the data section.

2.4. Data

The data employed in this study contain two major parts: production data and international trade data. The production data of minerals and chemicals are mainly from the United States Geological Survey (USGS), the China Nonferrous Metals Industry Association (CNMIA) and other related research institutions (AN, 2015; CNMIA, 2014; INN, 2015; Li, 2015; New Horizon, 2016; Signumbox, 2015). The productions of consumer electronics are from the statistical yearbooks of many countries (CCID, 2015a,b; NBSC, 2016; Trade Stastics of Japan, 2016; USCB, 2016). The productions of EVs and PHEVs are compiled based on multiple data sources (CAAM, 2016; CBA, 2015; CBN et al., 2015; CHYXX, 2016; CIAPS, 2016). The national import and export data are mainly adopted from every country's customs database, the UN comtrade database, and Eurostat database by the customs code of a specific product (CCIN, 2016; Database Eurostat, 2016; KCS, 2016; Trade Stastics of Japan, 2016; UN Comtrade, 2016; Zauba, 2016). The conversion coefficients used in this study are adopted from Hao et al. (2017), as shown in Table 2.

This study is based on intensive data collection and investigation. Even though there is high confidence on the effective coverage of existing data sources, the obtained data is not enough to calibrate all the lithium flows for the selected countries. Both production data and trade data need further treatment to fill the data gaps. Data treatment is conducted based on three major assumptions. First, the trade volumes of LIB cathode materials are only available in China, South Korea and Japan, while not available in other countries. Based on the understanding that the production and consumption of LIB cathode materials

Table 2
The conversion coefficients of major lithium commodities.

Commodity	Conversion coefficient	Unit
Brines	0.60	t LCE/t
Ores	0.16	t LCE/t
Lithium carbonate	1.00	t LCE/t
Lithium hydroxide	0.88	t LCE/t
Lithium chloride	0.87	t LCE/t
Lithium concentrate	0.18	t LCE/t
LMO	0.20	t LCE/t
LCO	0.38	t LCE/t
LFP	0.23	t LCE/t
NCM	0.38	t LCE/t
LiPF	0.24	t LCE/t
LIB	0.15	t LCE/t
BEPV	14.9	kg LCE/item
BEB	49.7	kg LCE/item
PHEB	12.8	kg LCE/item
PHEPV	9.0	kg LCE/item
Electric bicycles	0.3	kg LCE/item
Mobile phones	4.8	g LCE/item
Portable computers	31.7	g LCE/item
Energy storage systems	0.59	t LCE/Wh

Note: Data from Hao et al. (2017).

mainly occurred in China, South Korea and Japan, LIB cathode materials trades among other countries are ignored. Second, sales data, which are normally quite adequate and clear, are used to approximate production data when production data is not available. For example, regarding electric vehicles, there is quite complete statistics on vehicle sales in major countries, while the statistics on production is not available in many countries. With the consideration that the sales and production of electric vehicles are generally balanced, this study assumes that the sales of electric vehicles are approximately equal to the production. Third, the production and trade of some lithium chemicals are too trivial to trace. For example, lithium tritide is used for manufacturing hydrogen bombs. The global trade volume of lithium tritide is lower than 10 kg. Under such a circumstance, the lithium tritide flow has little impacts on the global flow of lithium commodities. For this reason, the flows of these chemicals are ignored in this study.

3. Results

3.1. Global overview

The overview of global production and trade of lithium commodities is shown in Fig. 3. The histogram in each country represents the productions of major lithium commodities. The arrow lines represent the international trade flows. The trade volumes are annotated beside the arrow lines.

Regarding the production of lithium commodities, it can be found that Chile, Australia, the United States, Argentina, and China were the leading countries in the resource mining stage. The chemical productions also mainly occurred in these countries. Among these countries, China had the largest lithium chemical yield. In the product manufacture stage, LIBs productions were concentrated in China, South Korea and Japan.

As for the international trade, results indicate that the trade of lithium commodities existed quite commonly all around the world. The trades of lithium minerals were mainly originated from Chile and Australia, flowing to other countries. The brines trades were mainly from Chile to China (5.8 kt LCE). The trades of lithium ores were mainly from Australia to China (40.4 kt LCE). In the chemical production stage, the largest trades of lithium chemicals were lithium carbonates trades from Chile to South Korea (13.8 kt LCE), followed by lithium concentrates trades from Australia to China (13.1 kt LCE). In the product manufacture stage, the LIBs trades were dominated by the trades from South Korea to China (4.5 kt LCE), followed by the trades from Japan to the U.S. (2.9 kt LCE). For the LIB-containing products, the largest trade flow was from China to the U.S. (1.1 kt LCE). The intuitive global flow of lithium commodities is shown in Fig. 4.

3.2. Production perspective

Figs. 5 and 6 show the breakdowns of lithium commodity production by country and by commodity type, respectively. In the resource mining stage, the total lithium mineral production was 171 kt LCE, of which the productions in Australia, Chile, China, and Argentina accounted for 94%. Among these countries, Chile had the largest lithium brine production (62 kt LCE), and Australia had the largest lithium ore production (71 kt LCE). Brines accounted for 56% of total mineral production, 12% higher than the contribution from ores.

In the chemical production stage, China had the highest production of basic chemicals, with 40.7 kt LCE lithium carbonate, and 20.5 kt LCE lithium hydroxide. Chile produced 55.1 kt LCE lithium carbonate. Argentina produced 11.7 kt LCE lithium carbonate and 6.4 kt LCE lithium chloride. Regarding the chemical derivatives, the production of LIB cathode materials accounted for 68% of the total. The production of NCM was the largest (24.8 kt LCE), followed by LCO (24.3 kt LCE). The production of LIB cathode materials mainly occurred in China, South Korea, and Japan. China was the largest producer of chemical derivatives, including lithium chloride (12.3 kt LCE), LMO (2.5 kt LCE), LCO (16.2 kt LCE), LFP (2.8 kt LCE), NCM (11.9 kt LCE), and LiPF (1.3 kt LCE).

In the product manufacture stage, China was the largest LIB producer with 31.7 kt LCE lithium consumed, followed by South Korea with 14.1 kt LCE lithium consumed. The lithium consumed to produce LIBs accounted for 30.4% of the global lithium consumption.

Fig. 7 shows the breakdown of LIB consumption by the applications. In 2014, the dominating application of LIBs was consumer electronics, accounting for 75% of total LIB consumption. China had the highest lithium consumption in producing mobile phones (8.1 kt LCE) and portable computers (9.8 kt LCE), accounting for 96% of the global total. The LIBs used for EVs accounted for 24% of total LIB consumption. The productions of BEBs and PHEBs mainly occurred in China with a total lithium consumption of 0.9 kt LCE. China was also the leading producer of electric bicycles (1 kt LCE). The U.S. was the leading lithium consumer in producing electric passenger vehicles (1.6 kt LCE), followed by the EU (1.3 kt LCE). Besides, a small amount of LIBs was used in the production of energy storage systems.

3.3. International trade perspective

The import and export of lithium commodities in each country are shown in Fig. 8. Total lithium minerals trade reached 47 kt LCE, accounting for 28% of the lithium mineral production. On the export side, the major producing countries played the leading roles. Chile had the largest brines export (6.7 kt LCE). Australia was the leading country of lithium ores export (40.4 kt LCE). On the import side, China had the largest lithium mineral import (46.2 kt LCE), of which the import of lithium ores accounted for 87%.

Regarding the trade of lithium chemicals, total trade volume reached 132 kt LCE, accounting for 53% of the total production. Chile, Australia and Argentina were the leading exporting countries. Chile was the largest lithium carbonate exporter (52.9 kt LCE), and Argentina was the largest lithium chloride exporter (6.1 kt LCE). Australia exported the largest amount of lithium concentrate (30.4 kt LCE). The U.S., China, Japan, South Korea and EU were the major importing countries, accounting for 88% of total import. Among these countries, South Korea, with 14.9 kt LCE lithium carbonate imported, was the largest importing country.

In the product manufacture stage, the total trade volume of LIBs and LIB-containing products reached 30.3 kt LCE, accounting for 42% of the

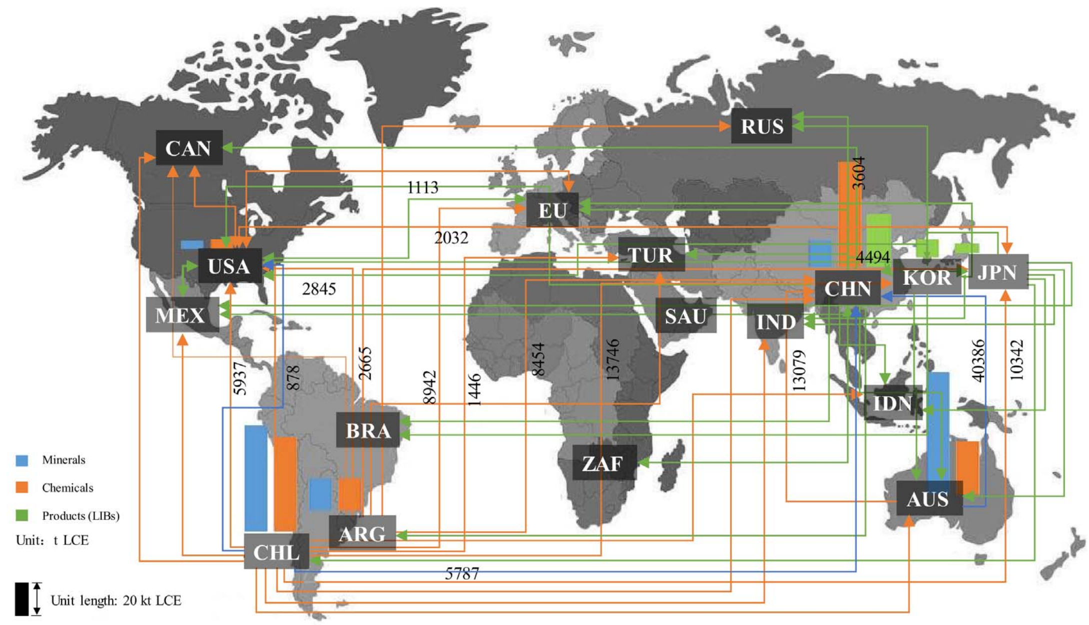

Fig. 3. Overview of global lithium commodity production and trade.

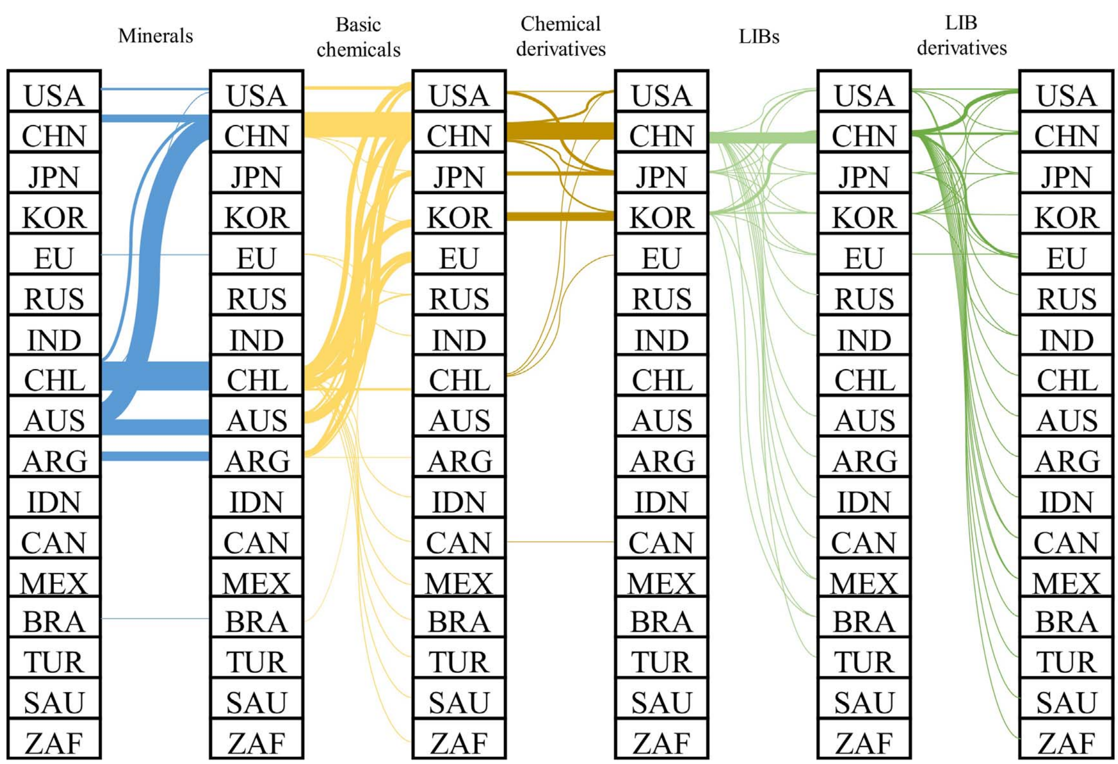

Fig. 4. Trade-linked global flow of lithium commodities.

production. On the export side, South Korea was the largest exporter of LIBs (8.4 kt LCE), followed by China (8.2 kt LCE). On the import side, China imported the largest amount of LIBs (5.5 kt LCE), followed by the U.S. (5.1 kt LCE) and the EU (5.1 kt LCE). Regarding LIB-containing products, China was the leading exporter of mobile phones (3.3 kt LCE) and portable computers (7 kt LCE). The U.S. was the biggest importer of mobile phones (1.2 kt LCE) and portable computers (2.9 kt LCE).

Fig. 9 presents the decomposition of international trade by commodity type. Lithium carbonate, ores, and lithium concentrate were the three dominating trade commodities, altogether accounting for 65% of total trade volume. This implies that lithium trade mainly occurred in the forms of mineral trade and chemical trade.

3.4. Discussions

This study reveals a quite vigorous lithium commodity system in terms of both production and international trade. With the market penetration of next-generation clean technologies, represented by EVs, the lithium consumption is highly likely to continuously rise in the future. Based on this consideration, the resource security and utilization

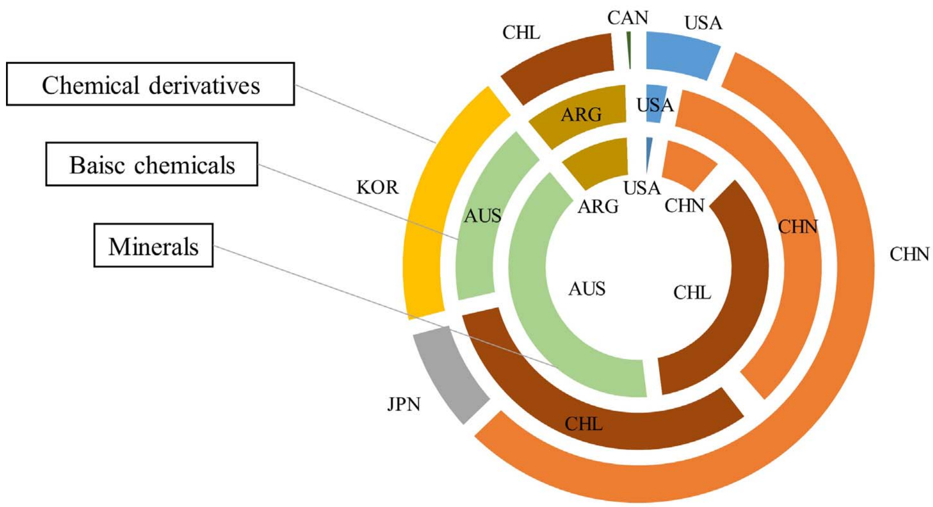

Fig. 5. Breakdown of lithium commodity production by country.

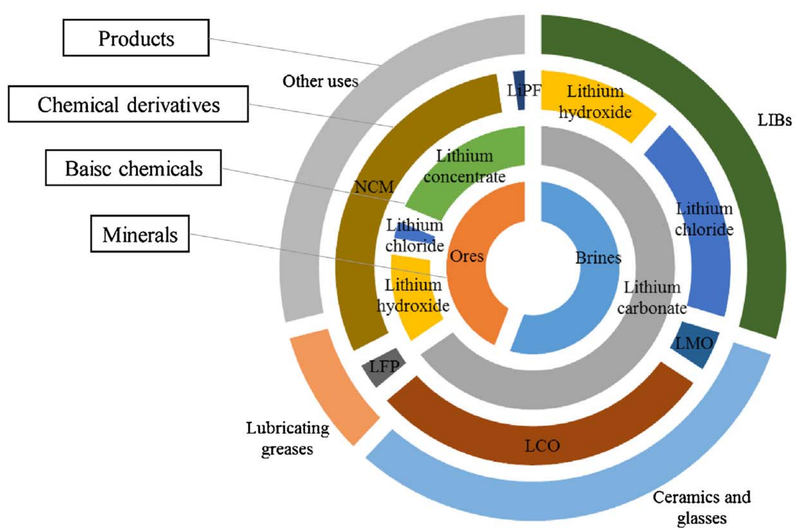

Fig. 6. Breakdown of lithium commodity production by commodity type.

efficiency of lithium should be paid high attention.

It can be found that the production and international trade of lithium commodities are dominated by a few countries in many stages. Especially, the global lithium resources and chemicals supply are highly dependent on Chile and Australia. If lithium supply in these two countries encounters fluctuations due to some economic or political reasons, the balance between global lithium supply and demand might break down in a short time. For the countries dependent on large-volume upstream lithium commodity imports, such as China, the high dependence is a potential risk from the resource security perspective.

Under such a circumstance, national policies for setting up the country's lithium reserves should be considered for the strategic economic reason. There are two major ways to improve lithium resource security. One way is to increase primary resource supply through more intensive domestic resource mining or more aggressive import. The other way is to increase secondary resource supply through well-established recycling system. The recycling potentials of various lithium-containing commodities are different. LIBs represent the major opportunity for lithium recycling, considering their high lithium intensity, large market demand and mature recycling technologies. It is necessary for the government to establish a comprehensive LIB recycling system.

From the supply chain perspective, there is significant potential for supply chain optimization, which helps to avoid unnecessary international trade and improve resource efficiency. For example, many LIB cathode materials were firstly produced in China, then exported to South Korea to produce LIBs, and finally imported back by China to produce EVs. The reason why LIBs production were not carried out in China is that China lacks the capacity for producing high-quality traction batteries for EVs. This situation can be improved by China's own technology update, or technology transfer through establishing joint ventures with foreign companies.

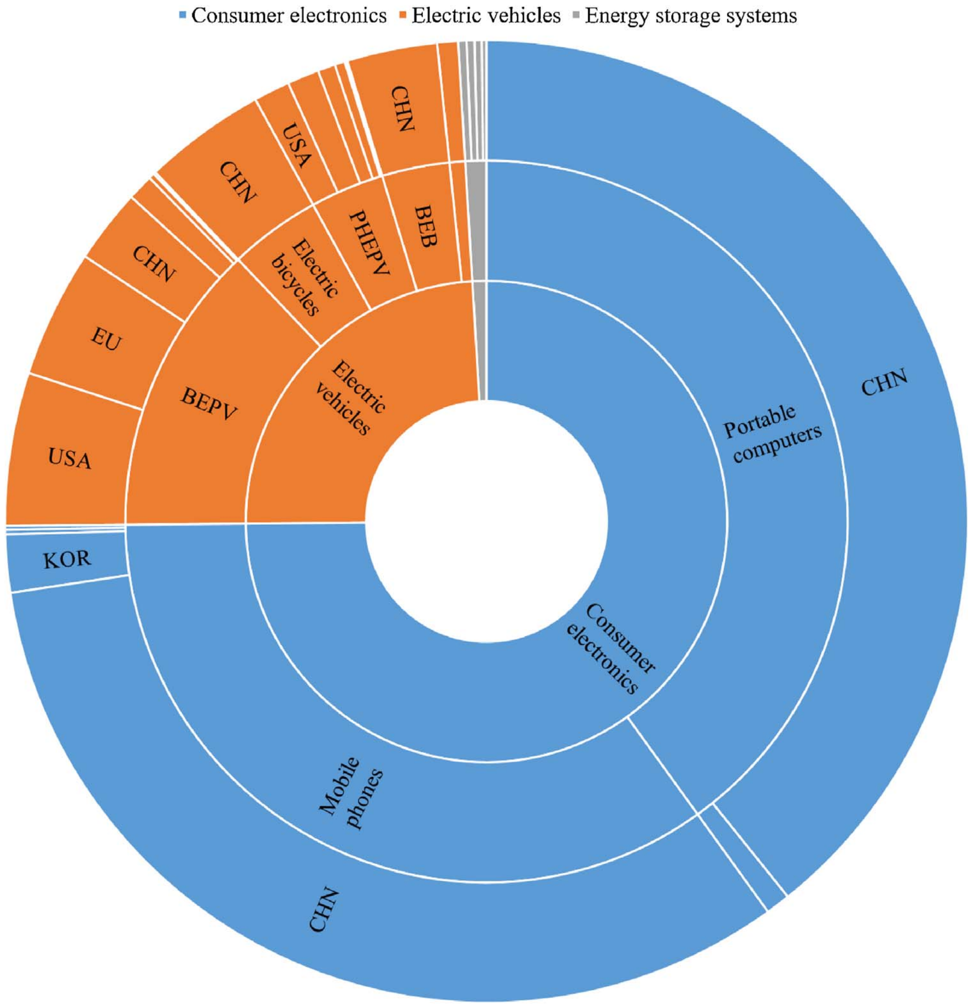

Fig. 7. Breakdown of LIB consumption by applications.

The environmental impacts of the lithium trade ought to be paid high attention. The globally distributed trade of the lithium commodities leads to the difficulty for waste management. It is hard for the product manufacturers in one country to trace the life cycle of the products after their export to another country. For this reason, the cooperation between trade partners in waste management is very essential. They should take their respective responsibilities in establishing a cross-border recycling system. The trade partners can do this work by sharing the information, related equipments, etc.

4. Conclusions

Lithium is an indispensable ingredient for the modern industry. Globally, the production and consumption of lithium kept rapid growth over recent years. This trend is predicted to continue with the development of next-generation clean technologies, especially EVs. Given this background, this study establishes a trade-linked MFA framework to trace the lithium flow both along its life cycle on the national level and international trade on the global level.

The results show that global lithium production reached 171 kt LCE in 2014. Chile and Australia had the highest mineral productions, most of which were used for domestic chemical production. China was the major lithium chemical producer (61 kt LCE). The lithium consumed for the production of LIBs was 52 kt LCE. The LIB production mainly occurred in China, South Korea, and Japan. Consumer electronics were the main application of LIBs in 2014. From the international trade perspective, the trade of lithium commodities existed quite commonly around the world. The trade of lithium minerals was mainly from Chile and Australia to other countries. The major origins of lithium chemicals were Chile, Australia and Argentina. China was the major destination of lithium minerals and chemicals. The trade of lithium carbonate had the largest share of total lithium commodity trade (33%).

This study represents one of the first trials in depicting a trade-linked global lithium flow. Further researches can be conducted by expanding the system boundary to include the product use stage and waste management stage. More lithium-containing products might be considered in the product manufacture stage. The temporal boundary can also be further expanded from a single year to a full time series.

Acknowledgements

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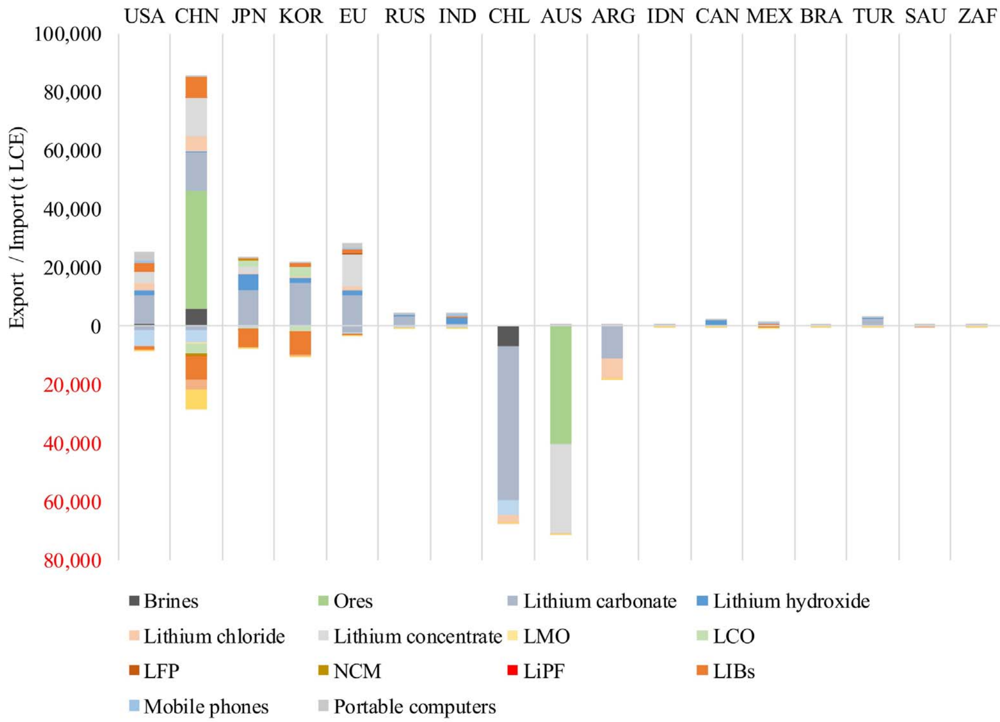

Fig. 8. The import and export of lithium commodities in each country.

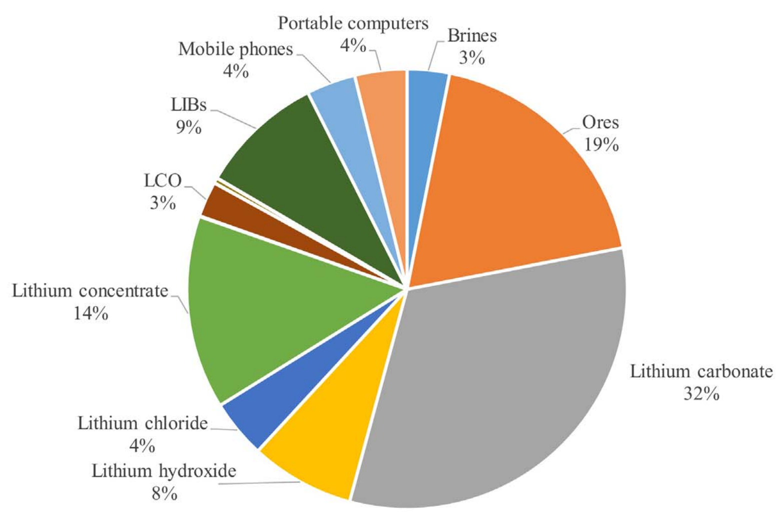

Fig. 9. Decomposition of international trade by commodity type.

Appendix A

A1. Data of Fig. 5 (unit: kt LCE)

Countries	Minerals	Basic chemicals	Chemical derivatives
USA	4.6	5.5	5.1
CHN	15.0	61.2	47.0
JPN	0.0	0.0	6.7
KOR	0.0	0.0	15.5
EU	1.6	1.6	0.0
RUS	0.0	0.0	0.0
IND	0.0	0.0	0.0
CHL	61.7	55.1	7.6
AUS	70.8	30.4	0.0

ARG	18.1	18.1	0.0
IDN	0.0	0.0	0.0
CAN	0.0	0.0	1.1
MEX	0.0	0.0	0.0
BRA	0.9	0.9	0.0
TUR	0.0	0.0	0.0
SAU	0.0	0.0	0.0
ZAF	0.0	0.0	0.0

A2. Data of Fig. 6 (unit: t LCE)

Commodity	Minerals	Basic chemicals	Chemical derivatives	Products
Brines	95,551			
Ores	75,622			
Lithium carbonate		112,072		
Lithium hydroxide		20,500	9390	
Lithium chloride		6423	14,901	
Lithium concentrate		32,178		
LMO			3749	
LCO			24,292	
LFP			2857	
NCM			24,798	
LiPF			1872	
LIBs				51,965
Ceramics and glasses				55,286
Lubricating greases				15,549
Other uses				50,103

A3. Data of Fig. 7 (unit: t LCE)

Application	Commodity	Country	Value
Consumer electronics	Mobile phones	USA	0
		CHN	8120
		JPN	38
		KOR	485
		EU	0
		RUS	0
		IND	33
		CHL	0
		AUS	0
		ARG	0
		IDN	0
		CAN	0
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
	Portable computers	USA	Not available
		CHN	9781
		JPN	206
		KOR	0
		EU	0
		RUS	0
		IND	0
		CHL	0
		AUS	0
		ARG	0
		IDN	0
		CAN	0
		MEX	0
		BRA	0

		TUR	0
		SAU	0
		ZAF	0
Electric vehicles	BEPV	USA	1281
		CHN	622
		JPN	218
		KOR	8
		EU	1070
		RUS	0
		IND	0
		CHL	0
		AUS	11
		ARG	0
		IDN	0
		CAN	47
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
	PHEPV	USA	303
		CHN	146
		JPN	85
		KOR	3
		EU	267
		RUS	0
		IND	0
		CHL	0
		AUS	4
		ARG	0
		IDN	0
		CAN	17
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
	BEB	USA	Not available
		CHN	755
		JPN	0
		KOR	0
		EU	Not available
		RUS	0
		IND	0
		CHL	0
		AUS	0
		ARG	0
		IDN	0
		CAN	0
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
	PHEB	USA	Not available
		CHN	174
		JPN	0
		KOR	0
		EU	Not available
		RUS	0
		IND	0
		CHL	0
		AUS	0
		ARG	0
		IDN	0

		CAN	0
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
	Electric bicycles	USA	Not available
		CHN	1023
		JPN	Not available
		KOR	0
		EU	Not available
		RUS	0
		IND	0
		CHL	0
		AUS	0
		ARG	0
		IDN	0
		CAN	0
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0
Energy storage systems	Energy storage systems	USA	70
		CHN	60
		JPN	40
		KOR	Not available
		EU	65
		RUS	0
		IND	0
		CHL	0
		AUS	0
		ARG	0
		IDN	0
		CAN	0
		MEX	0
		BRA	0
		TUR	0
		SAU	0
		ZAF	0

A4. Data of Fig. 9 (unit: t LCE)

Commodity	Total trade value
Brines	6665
Ores	40,386
Lithium carbonate	68,988
Lithium hydroxide	16,380
Lithium chloride	9186
Lithium concentrate	30,416
LMO	111
LCO	5572
LFP	44
NCM	803
LiPF	51
LIBs	19,528
Mobile phones	7729
Portable computers	8202

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