SCRREEN2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211.

Start date: 2020-11-01 Duration: 36 Months

FACTSHEETS UPDATES BASED OF 2020 FACTSHEETS

LITHIUM

AUTHOR(S):

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LITHIUM

OVERVIEW

Lithium (chemical symbol Li) is a silver-white to grey metal belonging to the alkali metal group. With a density of only 0.53 g/cm3, lithium is the lightest metal and the least dense solid element at room temperature. Also, lithium has excellent electrical conductivity and the highest electrochemical potential of all metals. Due to its high reactivity lithium only occurs in nature in the form of inert mineral compounds such as silicates, or, in general, as chloride in brines and seawater.

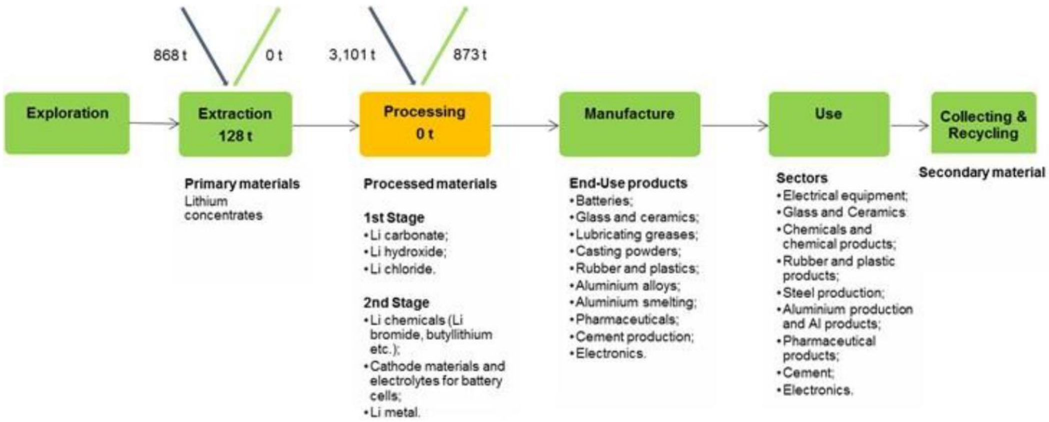

Figure 1: Simplified value chain for lithium[1] for the EU, averaged over 2012-2016

Table 1. Lithium extraction supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
76,213	Australia 53% Chile 24% China 10% Argentina 8%	1,377	1.8%	Other 81% Portugal 19%	81%

Table 2. Lithium processing supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
57,159	China 56% Chile 32% Argentina 11%	1,832	3.2%	Chile 79% Switzerland 7% Argentina 7% USA 6%	100%

[1] JRC elaboration on multiple sources (see next sections)

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Prices: Between 2016 and 2018, , the increase of lithium price was due to an increment of demand for electric vehicles and stationary storage for renewable energies (Brown et al., 2020; DERA, 2021a; S&PGlobal, 2021). For 2019-2020, lithium prices decreased as a response to lithium supply overshooting demand. In spite a decreasing demand at the beginning of 2020, there was an increase of lithium demand in the second half of 2020 as a result of the relaxation of COVID-19 measures in the US and Europe and the reactivation of global supply chains (USGS, 2021). Considering a low lithium price and a potential growing demand (e.g., for e-mobility), lithium prices are expected to rise for 2021 and the upcoming years (Barrera, 2021b).

Primary supply: From 2010 to 2020, the global production of lithium raised from 28,100 tonnes to 95,000 tonnes (lithium content, Statista 2021). Same level of information can be obtained from World Mining Data with a production in Li2O content increasing from 52,000 tonnes in 2008 to about 200,000 tonnes in 2018 .

In 2019, Lithium was currently extracted for more than 95% in Australia, Chile, China and Argentina. In Australia and China, lithium is mainly extracted from hard rocks, whereas in Chile, and Argentina, lithium is extracted from brines (BGS, 2016)

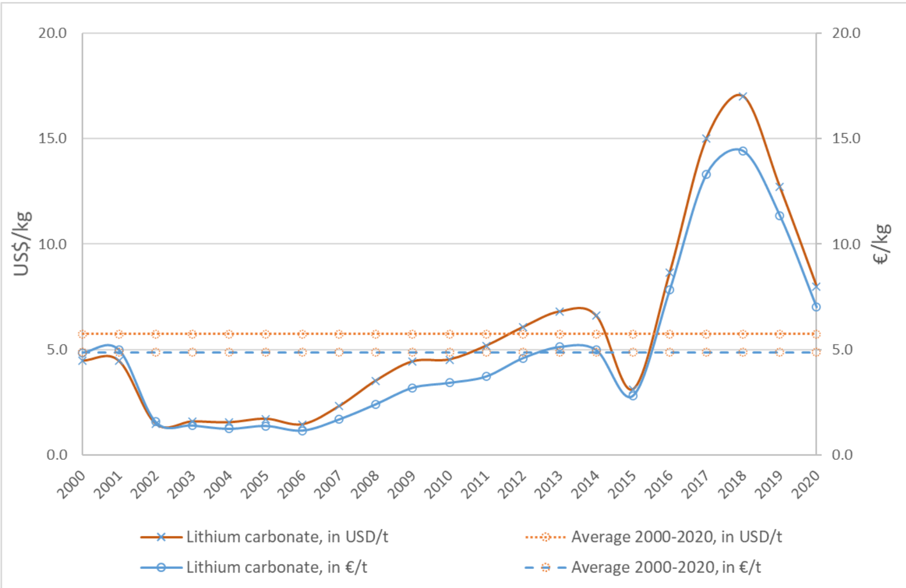

Figure 2. Annual average price of lithium between 2000 and2020 (USGS, 2021).

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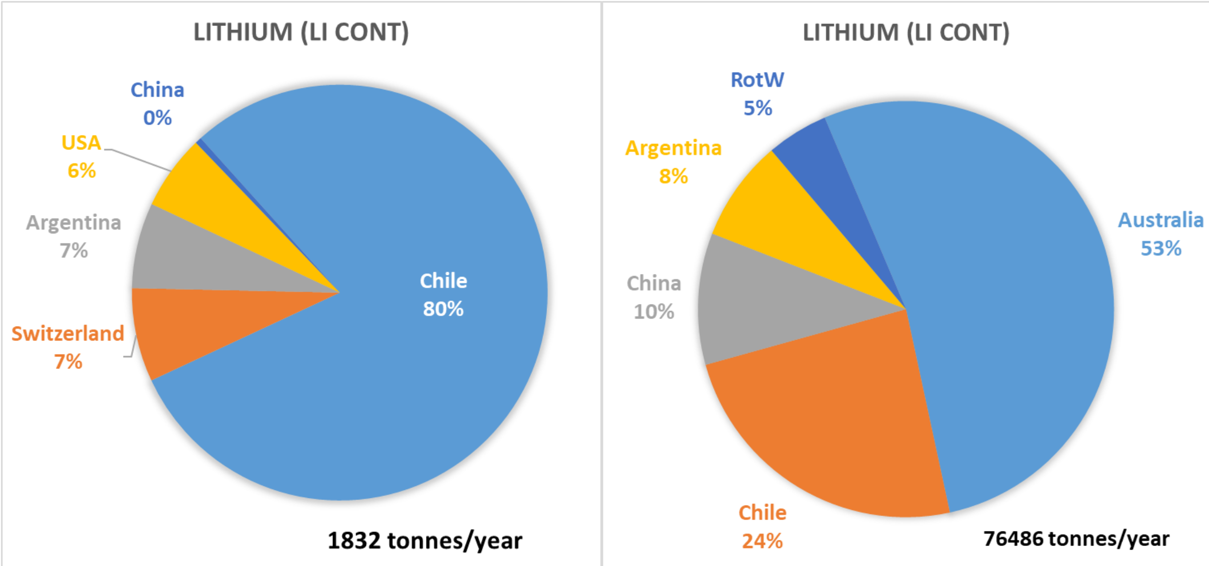

Figure 3. EU sourcing of processed lithium and global mine production (Li content) (average 2016-2020)

Secondary supply: Batteries could be the main (/only?) source of recycled lithium, but its recovery is still a challenge in 2021 due to high energy consumption. Cobalt and nickel remain the two target metals and the main value carriers though the recycling process. Lithium recovery is expected to be economic feasible during the next decade due to the capacity increase of the recycling plants. The production of Li_2CO_3 and LiOH end-products from the black mass (i.e. the scrap fraction material of electrodes after the mechanical removal of Al and Cu) through hydrometallurgy is the most possible commercial recycling scenario.

Uses: Technical-grade concentrates are used, with spodumene concentrates as the dominant input; lepidolite and petalite concentrates are used in lower quantities. Lithium carbonate is preferred when quality and other factors exclude the use of mineral concentrates. The technical applications of lithium are grouped in two categories: glass and ceramics covering about 66% and others including lubricating grease, cement production. Battery application remains very low in the EU.

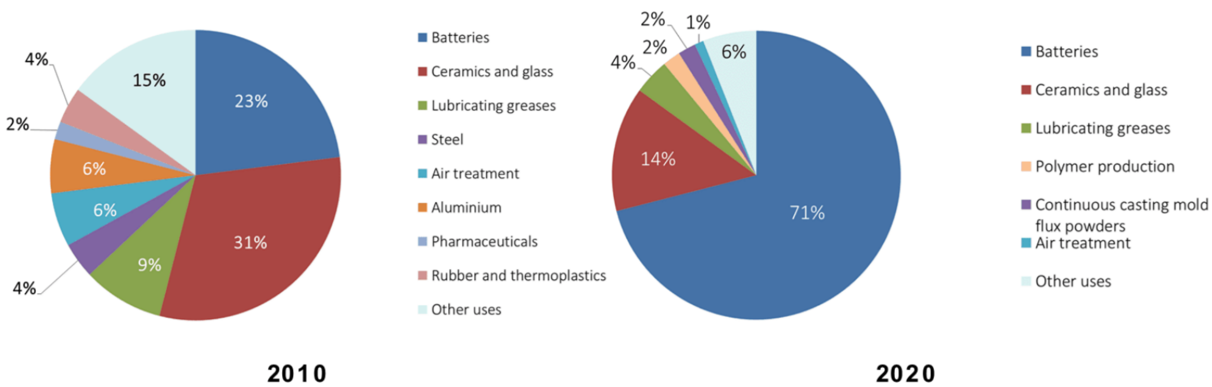

Figure 4: EU uses of lithium under any forms, : Evolution of the share of different sectors in lithium consumption between 2010 and 2020 (IFPEN 2021 based on USGS data)

Table 3. Uses and possible substitutes of lithium

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Application	Share	Substitutes	SubShare	Cost	Performance
		Potassium	25%	Similar or lower costs	Reduced
		Sodium	25%	Similar or lower costs	Reduced
		Aluminium	1%	Similar or lower costs	Reduced
Glass and ceramics	66%	Silicon	5%	Similar or lower costs	Reduced
		Calcium	10%	Similar or lower costs	Similar
		Polyurea	6%	Slightly higher costs (up to 2 times)	Similar
Lubricating greases	9%	Aluminium	4%	Similar or lower costs	Similar

Substitution: Substitution for lithium compounds is possible in many applications such as batteries, glass and ceramics, and greases (USGS 2019). However, there is often little incentive to use the available substitutes instead of lithium because of the relatively low lithium's price and the stability of its supply (BGS 2016).

Other issues: Lithium is classically not extracted from artisanal mining nor associated with Acid Mine Drainage (German Environment Agency, 2020). Moreover, it is extracted from deposits with a limited association of other heavy metals (German Environment Agency, 2020). The use/ban of lithium is restricted under REACH Regulation (EC) No 1907/2006 Annex XVII (Deutsche Forschungsgemeinschaft and Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, 2002). On 4 December 2019, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) submitted a proposal to the European Chemicals Agency (ECHA) for harmonised classification of lithium carbonate, lithium chloride and lithium hydroxide under the CLP Regulation (Classification, Labelling and Packaging of products), stating that "these three salts are hazardous to fertility and foetal development" (ANSES, 2020).

The CO_2 emissions from $LiOH.H_2O$ production range from 5.0 tonnes per tonne of $LiOH.H_2O$ (case of Chilean brine) to 14.8 tonnes of CO_2 per tonne of $LiOH.H_2O$ (Australian source of spodumene, processed in China; Grant et al., 2020). These results are in reasonable alignment with those of Kelly et al. (2021), who calculate a greenhouse gas footprint of 6.9 - 7.3 tonnes CO_2-eq/tonne $LiOH$-H_2O from lithium extracted from brine, and of 15.7 tonnes CO_2-eq/tonne $LiOH.H_2O$ for lithium extracted from ore processed in Australia with $LiOH.H_2O$ production in China. Moreover, "water" stands for a high risk regarding lithium exploitation (Lèbre et al., 2020), still with differences depending on the production routes.

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4. Lithium extraction supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
76,213	Australia 53% Chile 24% China 10% Argentina 8%	1,377	1.8%	Other 81% Portugal 19%	81%

Table 5. Lithium processing supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
57,159	China 56% Chile 32% Argentina 11%	1,832	3.2%	Chile 79% Switzerland 7% Argentina 7% USA 6%	100%

The lithium market size was estimated at 82 ktonnes in 2020 (USGS, 2021), with the lithium carbonate product segment dominating the market for the largest share of over 58% in 2020 in terms of volume (Grand View Research, 2021). Global lithium production was relatively flat from the late 1950s through to the early 1980s at levels of about 5,000 tonnes annually of lithium content (BGS, 2016). Since then it has increased by more than six times. In the last years in particular, world lithium mineral production rose from about 120 ktonnes lithium carbonate equivalent (LCE) (or 22.5 ktonnes of Li) in 2007, to 194 ktonnes LCE (or 36.5 ktonnes of Li) in 2016 at a compound annual growth rate (CAGR) of 5% per year. This is one of the highest CAGR observed for any mineral and metal (background data in Reichl, C.; Schatz, M; Zsak, 2019). The rapidly growing demand for lithium is driven by a strong growth rate in the demand for Li-ion batteries (Christmann et al., 2015). The value of world annual production was estimated at USD 4.23 billion in 2019 (Grandview-Research, 2021).

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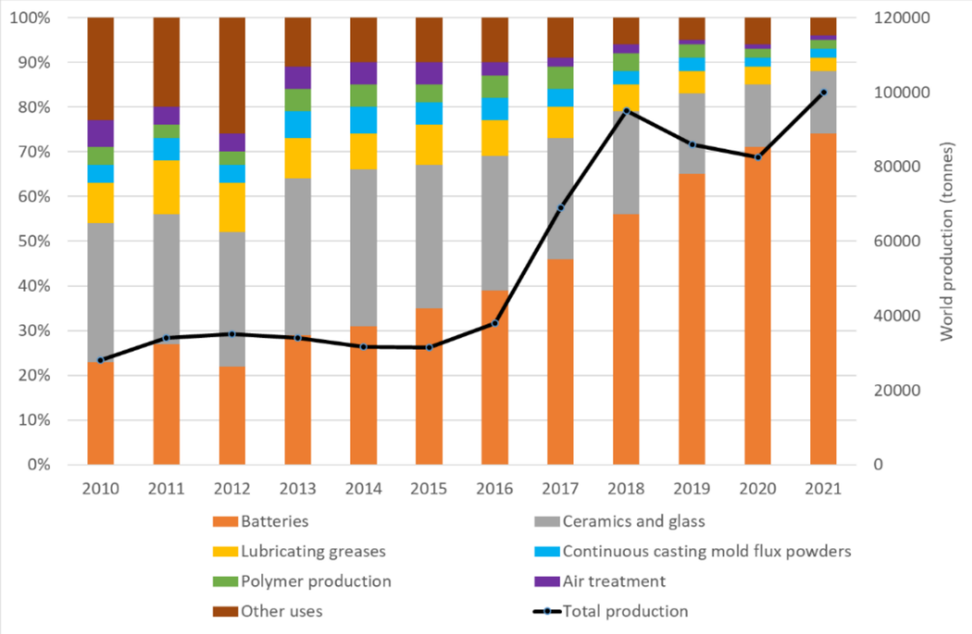

Figure 5. World lithium market by volume of products sold (Source: USGS)

Global end-use market is progressively moving from ceramics glass to batteries. In 2010, ceramics and glass represented more than 30% and batteries around 20%. In 2021, ceramics and glass represented only 14% whereas batteries represented almost 75%. The production has been multiplied by 5 between 2010 and 2021 (see Figure 5).

Lithium is currently produced from either hard-rock mineral deposits or brines. While in the past, lithium was produced exclusively from hard-rock lithium silicate minerals, the lower production costs from lithium-rich brines made the latter increasing its share for lithium production since the early 1980s (BGS, 2016; Hocking, 2016). In 2017 and 2018, there has been a sharp increase in supply from hard-rock mining, due to a massive ramp-up of lithium production in Australia. In 2018, hard-rock lithium supply surpassed that from brines, with a share of approximately 55% of the world lithium on producer of lithium mineral concentrate (spodumene), and most of the spodumene produced is exported for processing, mainly to China (BGS, 2016; USGS, 2021). However, the quantities involved are not reported by the usual sources of trade statistics as a specific trade code is missing.

China has most of the world's refining capacity, and as a result, plays a significant role in the exports, imports and consumption of lithium. China produces large quantities of lithium carbonate and lithium hydroxide, mainly from mineral concentrates (spodumene), which are mostly imported from Australia (Heppel & Jeary, 2019; Hocking, 2016; USGS, 2021).

According to the World Integrated World Solution, in 2019, top exporters of lithium carbonates were Chile (€745,187.9K, 82,486,600 Kg), China (€ 142,473.4K, 12,933,100 Kg), Belgium (€ 67,695.9K, 6,880,120 Kg), European Union (€ 62,934.4K, 7,824,540 Kg), Netherlands (€ 55,463.3K, 6,210,760 Kg) (World Integrated World Solution, 2021). According to UN Comtrade, Chile was ranked as top exporter in 2019, together with Argentina, China, Belgium, the Netherlands and Germany. In 2019, Chile exported € 786M in Lithium carbonates, making it the 1st largest exporter of Lithium carbonates in the world (Observatory of Economic Complexity, 2021). The main destination of Lithium carbonates exports from Chile were South Korea (€ 268M),

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Japan (€ 192M), China (€ 103M), Belgium (€ 87M), and United States (€ 42M). However, in 2020, UN Comtrade reports top exporters as China (23%), Argentina (22%), Netherlands (14%), Belgium (11%) and Germany (9%), with total exports amounting to € 229 million. Chilean exports of lithium to China fell 90% during the first three months of 2019, which was attributed to the effects of the trade war between Washington and Beijing (S&P Global, 2019). According to the OEC, in June 2021 Chile's lithium carbonates exports accounted up to € 55M (Observatory of Economic Complexity, 2021).

Countries in Asia are the leading importers of lithium carbonates, i.e., South Korea (30%), China (25%), and Japan (19%). The total exports of lithium carbonates in 2020 amounted a total value of € 905 million (Figure 7). Regarding lithium hydroxide and oxide imports, China was the largest importer in 2020, 84% of the total exports amounting to €565 million (Figure 8).

Argentina removed an export tax of 5% imposed on lithium oxides and hydroxides and lithium carbonates at the end of 2015, a lift which was reconfirmed at the end of 2017 (OECD, 2021). However, the Government of Argentina announced the re-establishment of export duties in September 2018 on all tariff lines which will be in force until the end of 2020. The new export duties consist of a 12% increase with respect to the previously established export duty, but the maximum amount of tax to be paid is limited of USD 0.076 per USD of the FOB value entitled to the tax. The new export tax is applicable to lithium carbonates (CN 28369100) (GTA, 2018).

OUTLOOK FOR SUPPLY AND DEMAND

The global lithium market size is expected to grow at a compound annual growth rate (CAGR) of 1.9% from 2020 to 2027, driven by the demand for lithium-ion (Li-ion) batteries in various applications, especially the automotive industry (Grandview-Research, 2021). The market was negatively impacted by COVID-19 in 2020 as electronic vehicle (EV) and device manufacturing units were on temporary shutdown, which led to a decrease in the consumption of lithium batteries. However, as the lockdowns were lifted, the EV segment picked up the pace to meet the target emission standards set by many countries, which may enhance the demand for lithium batteries, and thus stimulate the demand for lithium in the coming years (Mordo-Intelligence, 2020). Despite the volatility brought by the coronavirus pandemic to every market, lithium has shown resilience and prices performed on an uptrend during the first quarter of 2021 (Barrera, 2021a).

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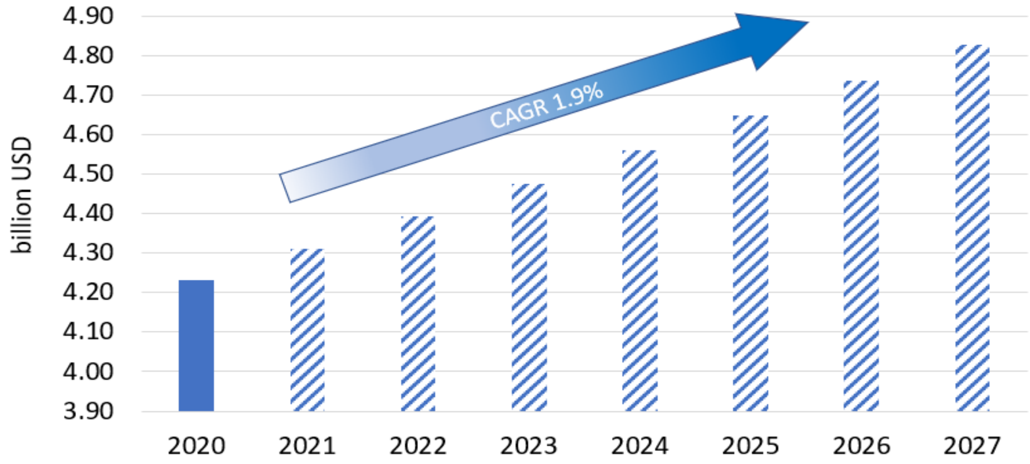

Figure 6: Global expected market size evolution of lithium (Grandview-Research, 2021)

Various estimates have been published on the outlook of lithium demand. They are based on different scenarios on the global deployment of electric vehicles, the vehicle types (e.g., plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs)), the evolution of the market growth for EVs, and the mix of battery chemistries. According to (Roskill, 2019), the lithium demand for batteries in 2028 is forecasted to be 1,130 ktonnes of LCE (or around 200 ktonnes of Li). The outlook report published by the International Energy Agency (IEA) in April 2021 shows that the EV fleets are expanding at a fast pace. In 2020, the global electric car stock hit the 10 million mark, a 43% increase over 2019 (IEA, 2021a). IEA estimates the lithium amount used in batteries for EVs sold in 2019 to be about 17 ktonnes. For battery needs in the 2030 Stated Policies Scenario, lithium demand expands to about 185 ktonnes/year while in the Sustainable Development Scenario, higher electric vehicle uptake leads to material demand values more than twice as high.

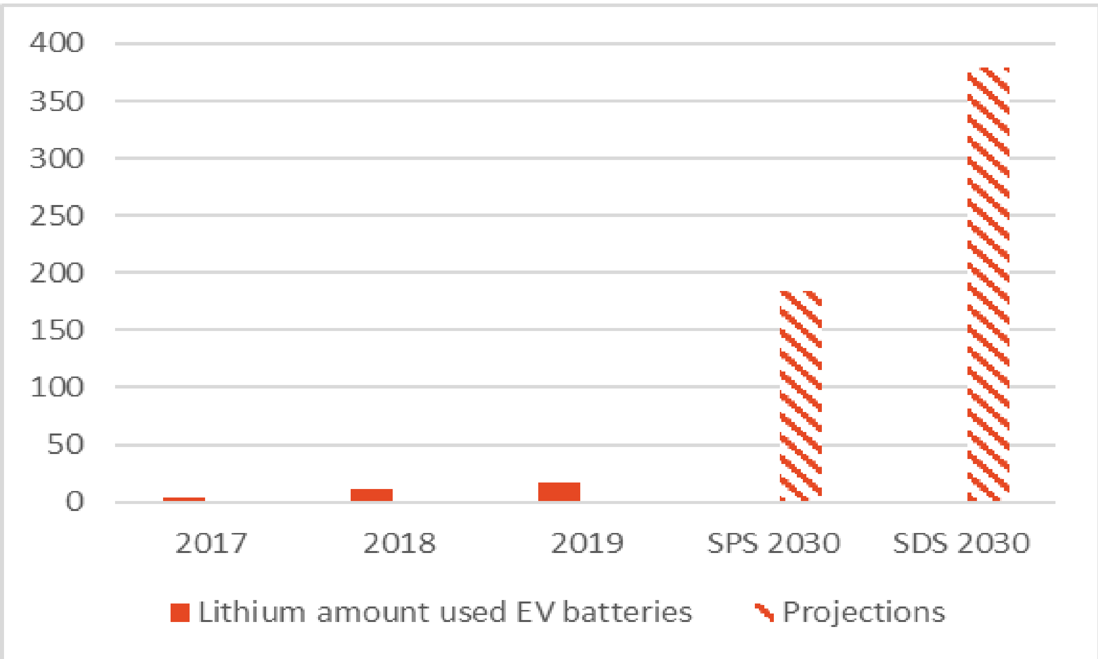

Figure 7: Amount of lithium used in EV batteries (IEA, 2021)

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In 2021, global demand for lithium-ion batteries is expected to rise from an estimated 47,300 tonnes in 2020 to 117,400 tonnes in 2024, according to a GlobalData report (Mining, 2021). This demand will be driven by a surge in EV sales, with annual production expected to increase from 3.4 million vehicles in 2020 to 12.7 million in 2024, with a corresponding increase in lithium-ion battery production, which is forecast to rise from 95.3 gigawatt-hours (GWh) in 2020 to 410.5 GWh over the same period. This global demand is expected to be led by China, with an increase in battery manufacturing capacity from an estimated 388.2 GWh in 2020 to 575.3 GWh in 2024, and increased EV sales. China's decision to cut subsidies in a phased manner until 2022, rather than eliminating it in 2020, is expected to provide an essential boost to the domestic market, as well as the overall global EV market.

The supply of lithium has to expand substantially to cover the demand from all end-use sectors, as well as to avoid shortages that may hinder the projected transition to electric mobility. The world output is expected to rise strongly in short to medium term (Schmidt, 2017; USGS, 2021) thanks to significant expansions in production capacity. Overall, the future availability of lithium depends on the prevailing prices, the discovery rate of economically exploitable deposits and investments made in their development, the progress in lithium recycling and battery design, substitution by solid state batteries etc. (Christmann et al., 2015).

Lithium supply security has become a top priority for technology companies in the United States and Asia, and as such strategic alliances and joint ventures among technology companies and exploration companies continue to be established to ensure a reliable, diversified supply of lithium for battery suppliers and vehicle manufacturers (USGS, 2021c).

EU TRADE

For the purpose of this assessment, lithium is evaluated at the processing stage.

Table 6. Relevant Eurostat CN trade codes for lithium

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**Title**
20121955 **20134350**	Lithium oxide and hydroxide Lithium carbonates	28252000 28369100	Lithium oxide and hydroxide Lithium carbonates

Figure 8 and 9depict the EU trade in processed lithium compounds (tonnes of lithium carbonates, oxide and hydroxide) between 2000 and 2021. Over the whole period, the EU was a net importer of lithium compounds: The yearly imports of lithium carbonates (CN 28369100) varied from 8,529 tonnes to 17,907 tonnes, while lithium-carbonate exports were in the range between 1,017 tonnes and 13,308 tonnes per year. The imports of lithium oxide and hydroxide (CN 28252000) varied between 1,894 tonnes in 2009 and 7,748 tonnes in 2007; the yearly lithium-oxide/hydroxide exports were significantly lower and varied between 276 tonnes and 2,314 tonnes.

Figure 10 and Figure 11 present the average EU imports of processed lithium compounds by country for the period 2000-2021. The major EU supplier of lithium carbonates was Chile, supplying 10,763 tonnes per year, which corresponds to ca. 83% of EU's lithium-carbonate imports. United States, China and Argentina followed with 7%, 3% and 3% of total lithium-carbonate imports to the EU, respectively. In the case of lithium oxide and

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hydroxide, the import situation was more diversified: Switzerland and Russia were the major suppliers of lithium oxide/hydroxide to the EU, covering ca. 31% (1,494 tonnes) and 20% (950 tonnes) of EU imports, respectively. Chile, United States and China followed with ca. 17%, 15% and 10% of EU's lithium oxide/hydroxide imports.

Trade of lithium-containing minerals (ores/concentrates) is not currently accounted in the EU's trade-flow statistics (Eurostat, 2021)

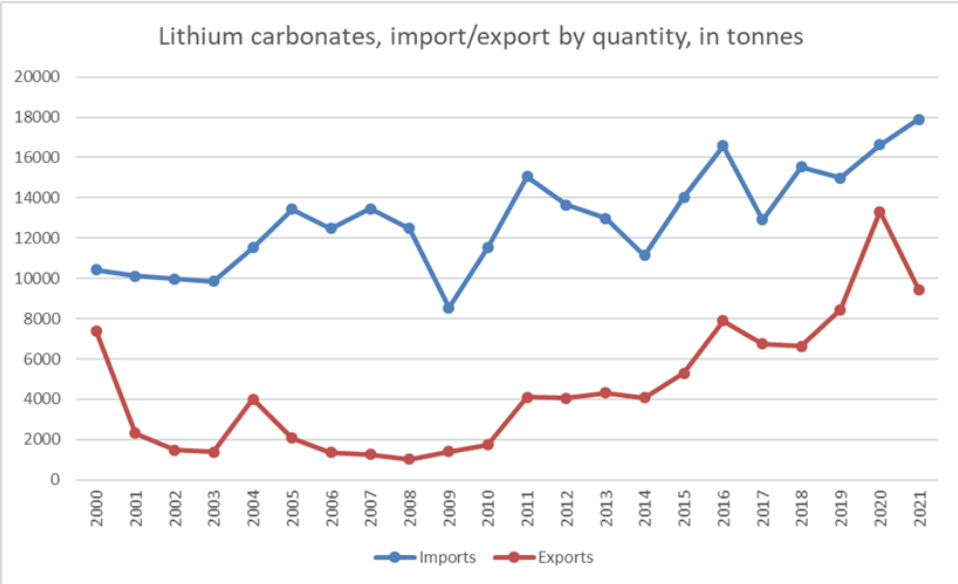

Figure 8. EU trade flows of lithium carbonates from 2000 to 2021 (based on Eurostat, 2021)

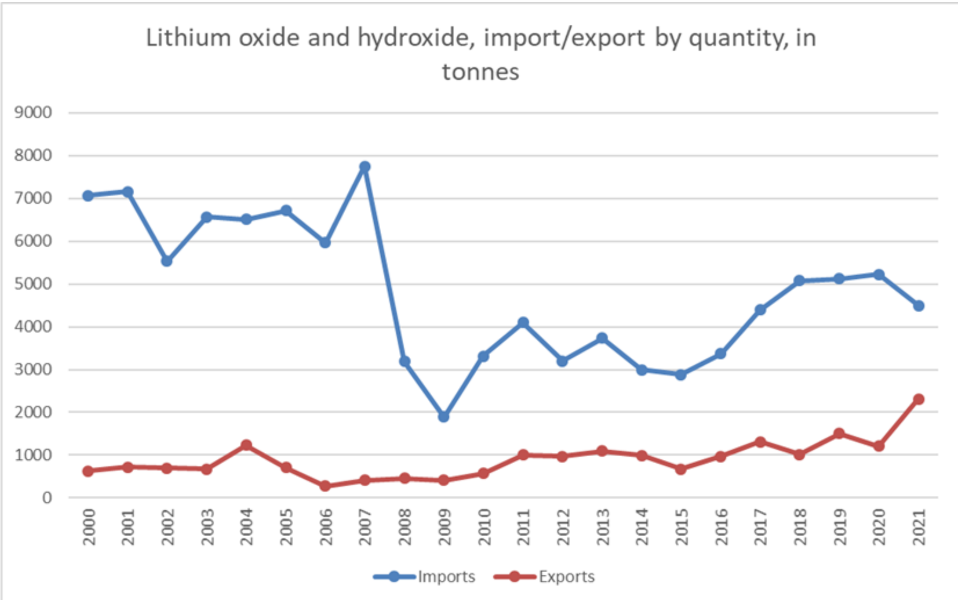

Figure 9. EU trade flows of lithium oxide and hydroxide from 2000 to 2021 (based on Eurostat, 2021)

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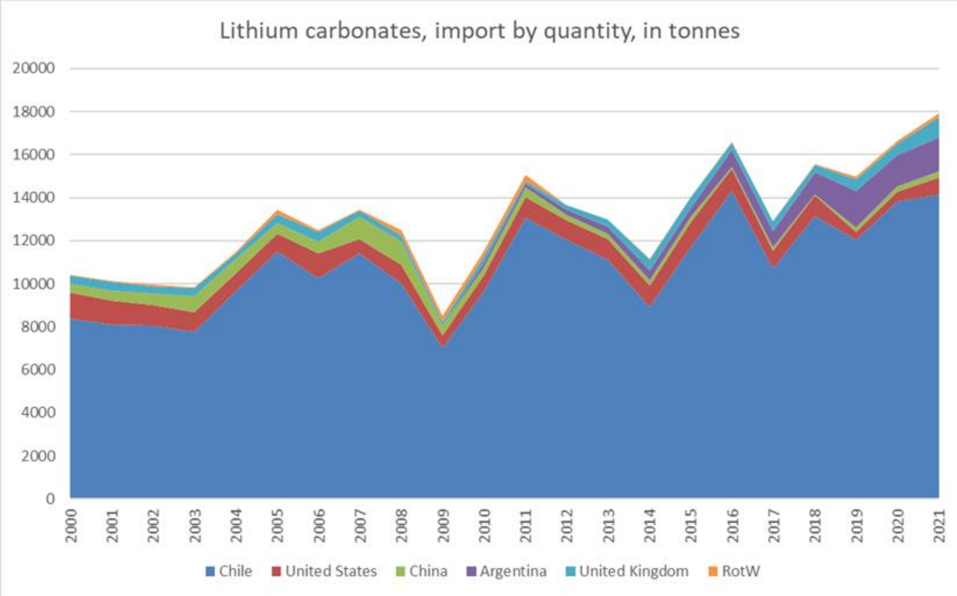

Figure 10. EU imports of lithium carbonates by country between 2000 and 2021 (based on Eurostat, 2021).

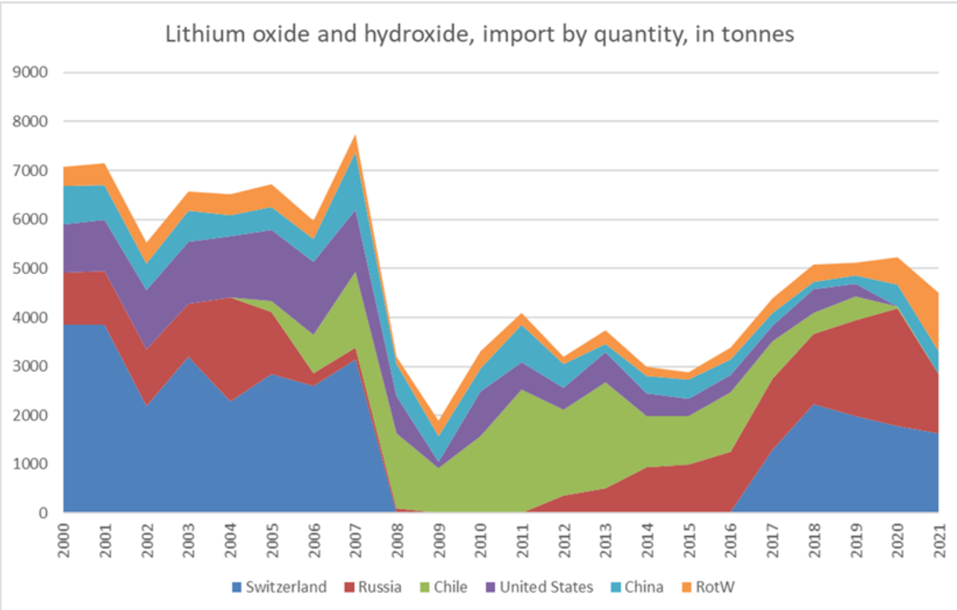

Figure 11. EU imports of lithium oxide and hydroxide by country between 2000 and 2021 (based on Eurostat, 2021).

PRICE AND PRICE VOLATILITY

Between 2016 and 2018, , the increase of lithium price was due to an increment of demand for electric vehicles and stationary storage for renewable energies (Brown et al., 2020; DERA, 2021a; S&PGlobal, 2021).

For 2019-2020, lithium prices decreased as a response to lithium supply overshooting demand. The reduction of demand for lithium batteries was associated with the COVID-19 impacts during the first half of 2020 (USGS, 2021). The price volatility of lithium carbonate was around 22% between February 2020 and January 2021

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(DERA, 2021c). In this period, average monthly prices fluctuated in a similar way as the prices between 2016 and 2020, where price volatility was 24%. Thus, the price volatility of lithium carbonate did not have major changes in 2016-2020.

In spite a decreasing demand at the beginning of 2020, there was an increase of lithium demand in the second half of 2020 as a result of the relaxation of COVID-19 measures in the US and Europe and the reactivation of global supply chains (USGS, 2021). Considering a low lithium price and a potential growing demand (e.g., for e-mobility), lithium prices are expected to rise for 2021 and the upcoming years (Barrera, 2021b).

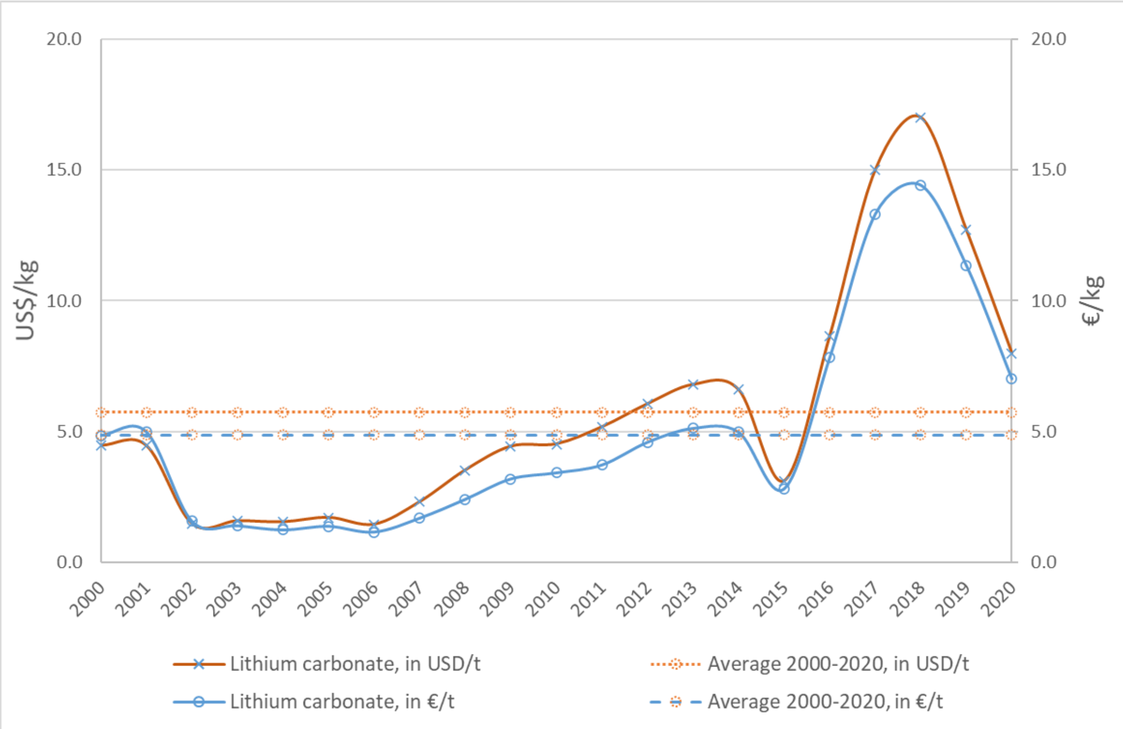

Figure 12. Annual average price of lithium and lithium carbonate in US$/kg and €/kg[2] (based on USGS, 2021). Dash lines indicates average price for 2000-2020

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

Annual average worldwide consumption of lithium is about 66,000 tonnes in Li content for 2019-2021 (Comisión Chilena del Cobre, 2022).

EU production and demand are only available for 2019 and 2020, and 2020 was highly impacted by Covid pandemic. The EU consumed annually about 5,000 tonnes of lithium in various end-uses in 2019. The EU

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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apparent consumption is estimated at approximately 3,758 tonnes of Li content for lithium oxide and hydroxide, and 1,305 tonnes of lithium content for lithium carbonates. The net import reliance as a percentage of apparent consumption is calculated at 25% for lithium oxide and carbonate in 2019.

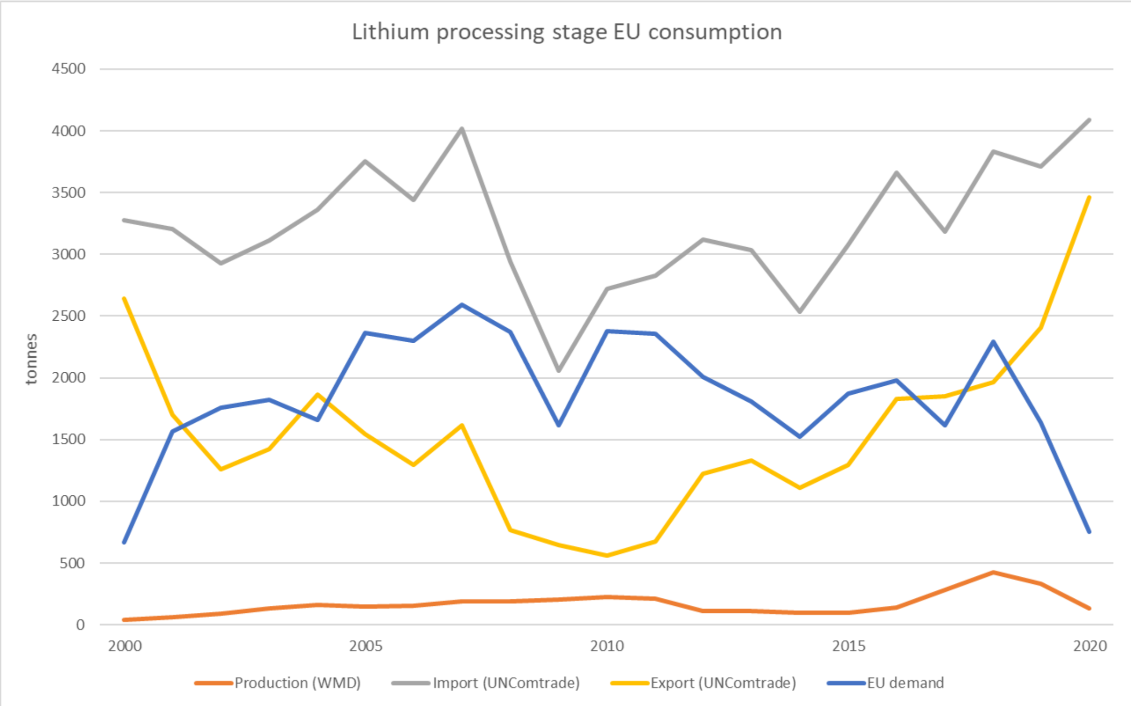

Figure 13. Lithium (HS codes 282520 and 283691) processing stage EU consumption. Production data from Eurostat Prodcom (2021) only available for years 2019-2020 and therefore, consumption is calculated only for years 2019-2020. Consumption is calculated in lithium content (EU production+import-export).

USES AND END-USES

Lithium's unique properties have resulted in many and diversified commercial applications. In 2018, the manufacture of rechargeable batteries was the main application of lithium accounting for more than half (51%) of global lithium demand of 49.8 ktonnes. With the electrification of the mobility sector currently under way and picking up speed, the demand for lithium-ion-batteries and therefore their share in overall lithium use has been quickly rising from 20% in 2008 to 51% in 2018 and even an estimate of 71% in 2020 (IFPEN 2021, European Commission 2010; Schmidt 2019; USGS 2021b) (**Erreur ! Source du renvoi introuvable.**). Other global markets for lithium products were glass and ceramics, 18%; lubricants, 9%; metallurgical powders, 3%; air treatment, 3%; and other uses, 15% (Schmidt 2019).

On regional level, the data availability for distribution of lithium uses is much lower. To the best of our knowledge, no recent data was published. This was confirmed by experts during a workshop on the lithium factsheet as well as during the research process. According to the available data set for 2012, the most significant demand market for lithium in the EU is the glass and ceramics industries, making up 66% of total demand in 2012 (BIO Intelligence Service 2015). The EU production of Li-ion batteries was and still is limited (Alves Dias et al. 2018). In 2019, only about 5% of global cell manufacturing capacity was located in the EU,

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with the major share in Poland and Hungary. However, growth rates for manufacturing capacity were higher in the EU than on global scale. Between 2012 and 2019, global capacity grew about 25-fold whereas European capacity increased 75-fold (Roskill 2020). It is expected that the European demand and likely the share of batteries in the distribution of uses grew alongside. Exact data is not available though. The shares of lithium use in the EU in 2010 and 2020 are provided in **Erreur ! Source du renvoi introuvable.**.

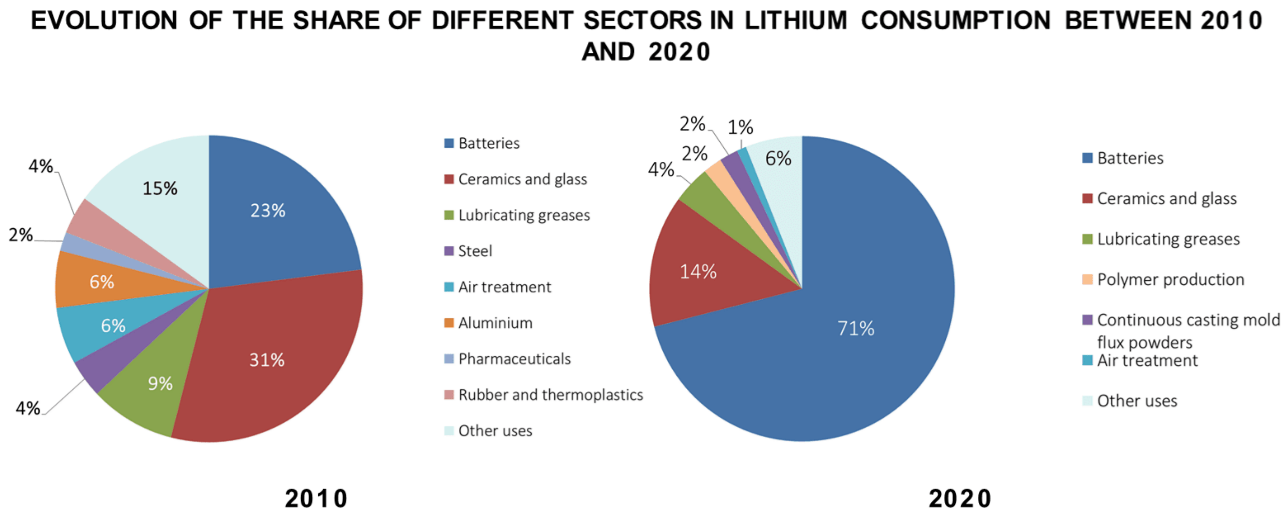

Figure 14. Global lithium end uses in 2010 and 2020 (IFPEN, 2021).

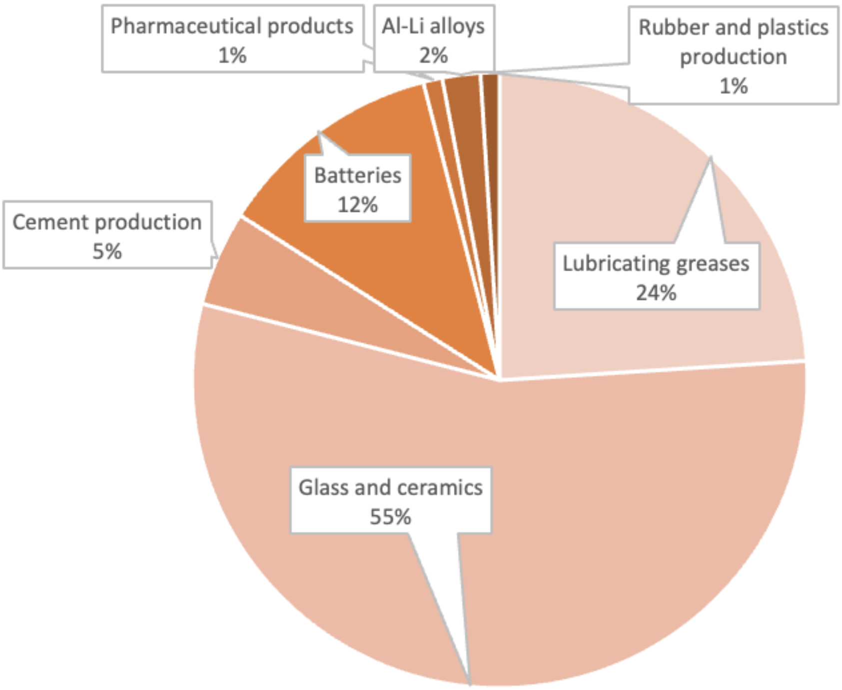

Figure 15. Lithium uses in the EU in 2016 (MSA 2020, SCRREEN experts, 2022).

Industry sectors relevant for lithium demand analysis are described in **Erreur ! Source du renvoi introuvable.** using the NACE sector codes (Eurostat, 2021). The development of gross value added by these sectors since 2000 is shown in Figure 20.

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Table 7. Lithium applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector for 2019 (*for 2014) (Eurostat 2021b)

Applications	2-digit NACE sector	Value added of NACE 2 sector (millions €)	Examples of 4-digit NACE sectors
Glass and ceramics	C23 - Manufacture of other non-metallic mineral products	72,396	C2311-Manufacture of flat glass; C2312-Shaping and processing of flat glass; C2313-Manufacture of hollow glass; C2319-Manufacture and processing of other glass, including technical glassware; C2340-Manufacture of other porcelain and ceramic products
Lubricating greases	C20 - Manufacture of chemicals and chemical products	117,150*	C2059 - Manufacture of other chemical products n.e.c.
Cement production	C23 - Manufacture of other non-metallic mineral products	72,396	C2351- Manufacture of cement; C2369-Manufacture of other articles of concrete, plaster and cement
Steel casting	C24 - Manufacture of basic metals	63,700	C2410 Manufacture of basic iron and steel and of ferro-alloys C2452- Casting of steel
Pharmaceutical products	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	94,336*	C2110 Manufacture of basic pharmaceutical products; C2120 Manufacture of pharmaceutical preparations
Rubber and plastics production	C22 - Manufacture of rubber and plastic products	94,767	C2219- Manufacture of other rubber products
Batteries and products containing batteries	C27 - Manufacture of electrical equipment	97,292	C2720- Manufacture of batteries and accumulators
Al-Li alloys	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	C2599 - Manufacture of other fabricated metal products n.e.c.

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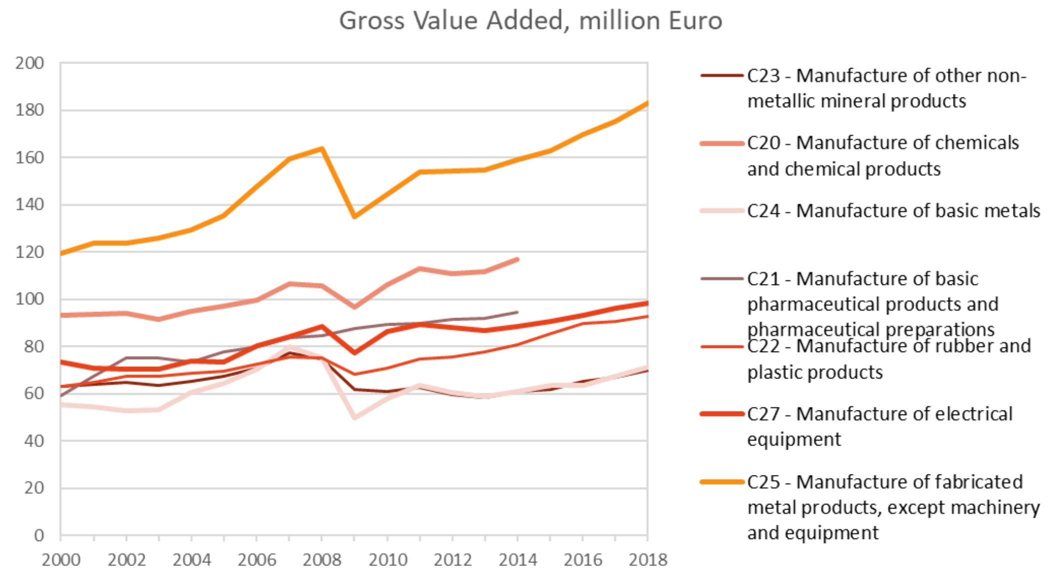

Figure 16: Value added per 2-digit NACE sector over time (Eurostat, 2021)

TECHNICAL APPLICATIONS

The technical applications of lithium are grouped in two categories: glass and ceramics, covering about 66%, and *others* including lubricating grease, cement production and battery applications, even though the latter remains very marginal in the European industry. Technical-grade lithium concentrates are used in several industrial applications, especially in the glass and ceramic sector, being spodumene concentrates the dominant raw material, while lepidolite and petalite concentrates are used in lower quantities. Lithium carbonate is preferred when quality and other factors exclude the use of mineral concentrates.

GLASS AND CERAMICS

In glassmaking, a small amount of lithia (lithium oxide - Li_2O, between 0.1 and 0.7%) is added as a flux to reduce by 25 ºC the glass melting temperature and to reduce viscosity, resulting in production cost savings as energy use is reduced by 5-10% (Christmann et al. 2015). Besides, glassware containing lithium is characterised by low thermal expansion, increased hardness and high temperature and thermal shock resistance. Lithium is added in the form of lithium concentrates containing silica and alumina and low Fe_2O_3 content to avoid undesirable discolouration in the products (M. Schmidt 2017). Applications include cookware, induction cooktops, safety glasses, fireplace windows, laboratory equipment, telescoping lenses etc.

In the ceramics industry, lithium is added as a fluxing agent, in the form of concentrated ore or lithium carbonate. In concentrations from 0.15% up to 2.5% (M Schmidt 2017), it reduces baking temperature and time, improves finishing characteristics and thermal shock resistance of porcelain enamels and glazes, and produces tiles with increased mechanical strength and low thermal expansion.

CASTING POWDERS

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Lithium in either carbonate or mineral form is used as an additive in mold flux powders for the continuous casting of steel, which is applied in 90% of global crude steel production, ensuring improved molten steel flow without casting defects.

CHEMICAL APPLICATIONS

A wide variety of lithium-containing products are commercially available. Their uses are listed below (BGS 2016), (M Schmidt 2017), (Hocking et al. 2016), (BRGM 2012):

- Lubricating greases: lithium is used as metallic hydroxide to produce metal soap by reacting with a fatty acid such as stearic acid. Metal soaps are used as thickening agents in lubricating greases.
- Aluminium production: lithium carbonate is used to reduce the melting point, increase electric conductivity, and reduce energy consumption of the aluminium production process.
- Aluminium alloy: aluminium-lithium alloys are used in the aeronautic industry for exceptional lightweight and elasticity.
- Steel production: lithium (either as lithium carbonate or in mineral form) is applied in continuous steel casting for increasing the melted metal fluidity and therefore optimise the process.
- Air treatment: lithium bromide and lithium chloride are both hygroscopic and are used as desiccants for gas streams, for example in air conditioning systems.
- Polymers production: organolithium compounds, including butyllithium, are used as reagents, catalysts, or initiators in the production of synthetic rubbers and plastics and for other similar chemical uses.
- Pharmaceutical: lithium carbonate and other Li compounds are used to treat psychiatric disorders, such as bipolar disorder, maniacal-depressive syndrome and depression, and non-psychiatric disorders. It is also used in the production of certain protease inhibitors in AIDS treatment.

BATTERIES

Lithium is one of the most attractive materials for batteries due to its high electrochemical potential combined with the lowest mass. It is used both in rechargeable and non-rechargeable batteries.

In non-rechargeable (or primary batteries) batteries, metallic lithium is used for the anode. These batteries are more expensive than most of other types of disposable batteries like alkaline batteries but are superior concerning operational lifetime, size, stability, and durability. Primary lithium batteries are employed in various household applications (e.g. calculators, cameras, and watches) and medical devices (e.g. heart pacemakers).

In rechargeable batteries, lithium is present in the electrolyte and the cathode of lithium-ion rechargeable batteries. The advantages of lithium-ion batteries compared to other battery types are outstanding energy and power density as well as long lifetime and cycle life. In the electrolyte, lithium salts (e.g. lithium-perchlorate ($LiClO_4$) are used together with organic solvents. In the cathode, several lithium-ion chemistries are currently in commercial use with a wide performance range and cost. The prevailing cathode compositions are NMC (lithium-nickel-manganese-cobalt oxide), LCO (lithium-cobalt oxide), LFP (lithium-iron phosphate),

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LMO (lithium-manganese oxide) and NCA (lithium- nickel-cobalt-aluminium oxide). Lithium carbonate and lithium hydroxide are the principal lithium compounds for the production of cathode materials.

Li-ion batteries are applied in a range of end-uses, while new applications still emerge. The largest market in 2015 was the portable electronic devices such as mobile phones, laptops, tablets, digital cameras, etc., corresponding to 65% of total Li demand for batteries (M Schmidt 2017). Since then, the emerging electronic vehicles sector has taken over as the largest market for lithium-ion batteries, in particular for full-battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), but also other forms of electric transportation such as bikes and scooters (Altura 2018). Furthermore, Li-ion batteries have found use in cordless heavy-duty power tools and medical devices (e.g. hearing aids). Finally, Li-on batteries have the potential to be utilised in off-grid and grid-connected energy storage systems.

LUBRICATING GREASES

Lithium is an additive to multi-purpose, high-performance lubricants. Lithium hydroxide monohydrate or lithium carbonate is mixed and heated with fatty acids to produce "lithium soap" grease, a thickening agent, which is combined within the lubricant's final formulation to ensure that lubrication properties are maintained over a wide range of temperatures and extreme load conditions. Lithium grease is one of the most used types of lubricating grease due to its cost-efficiency, excellent water resistance and effectiveness over a wide temperature range. It usually accounts for 6-15% of the final product; approximately 70% of all industrial lubricants produced globally contain lithium, typically at concentrations of 0.2 to 0.3% (Hocking et al. 2016).

PHARMACEUTICAL PRODUCTS

Some lithium-based compounds, including lithium carbonates, are used as antidepressants and mood stabilisers in the treatment of specific psychiatric disorders such as bipolar disorder, depression and other nervous problems. As lithium is being ingested, purity is essential.

PRIMARY ALUMINIUM PRODUCTION

Lithium carbonate or lithium bromide addition to the cryolite bath during aluminium smelting reduces the melting point, which decreases energy consumption, carbon cathode degradation and fluorine emissions.

ALUMINIUM ALLOYS

Metallic lithium is alloyed with aluminium to produce lightweight Al-Li and Al-Cu-Li alloys for the manufacture of specific parts in the aerospace industry where a combination of lightweight and high strength is required.

POLYMER PRODUCTION

Organolithium compounds such as butyl-lithium serve as catalysts or initiators for the manufacture of synthetic rubber products (e.g. styrene-butadiene, polybutadiene), commonly used in the manufacture of car tires.

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AIR TREATMENT

Lithium bromide and lithium chloride are among the best available hygroscopic substances for absorbing water; as a result, these salts found use as a desiccant to dehumidify the moist air, for example in large-scale air conditioning or air drying systems. Also, lithium hydroxide and lithium peroxide are used in scrubbers in enclosed environments (i.e. mining, space and submarine applications) to remove CO2 from the air.

OTHER APPLICATIONS

Lithium and other lithium-based compounds are present in smaller quantities in a broad range of minor applications such as:

- Electronics. Lithium niobate is used in optics and telecommunications;
- Nuclear. The ^{6}Li and ^{7}Li isotopes have applications in nuclear weapons and nuclear reactors;
- Textiles. Lithium acetate and lithium hydroxide are additives in textile dying;
- Cement. Lithium carbonate accelerates the hardening process of quick setting alumina cement;
- Fireworks. Lithium nitrate generates a red colour in fireworks;
- Rockets. Lithium metal and lithium hydrides are employed as high-energy additives in rocket propulsion.
- Water treatment. Lithium hypochlorite is used in swimming pool cleaning products;
- Welding. Lithium chloride is used as a flux in welding or soldering.

SUBSTITUTION

Substitution for lithium compounds is possible in many applications such as batteries, glass and ceramics, and greases (USGS 2019). However, there is often little incentive to use the available substitutes instead of lithium because of the relatively low lithium's price and the stability of its supply (BGS 2016).

In the article "On the materials basis of modern society" (Graedel et al. 2015b) 62 metals were considered for substitution. The process uses information that is similar to data presented in this factsheet, i.e. for each metal the uses were determined, the distribution of the elements total use and the best substitute for each use and the performance of that substitute. A qualitative assessment of the performance of the substitute was then provided, which was used to quantify that assessment. If all uses had a substitute that gave an exemplary performance, then the substitution index would be 0. Uses considered were at the global level and therefore were not US specific. Lithium was considered and was given a score of 41, thus representing a material that has fair substitutability.

GLASS AND CERAMICS

Sodium and potassium fluxes can be used instead of lithium in ceramics and glass manufacturing (Peterson 2017), but with a loss of performance, as they do not improve the thermal shock resistance to the same degree as lithium fluxes (Evans 2014).

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BATTERIES

In rechargeable batteries, a wide range of non-lithium types are available on the market, such as nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lead-acid batteries, with different advantages and disadvantages compared to lithium-ion types. Generally, the Li- ion battery is progressively replacing nickel batteries due to its better performance, particularly where a high-energy density and lightweight is required (Evans 2014). Lithium has become the preferred material for portable equipment and electric vehicle batteries (BRGM 2012), (Evans 2014). Nickel-metal hydride (NiMH) batteries compete with Li-ion batteries with good performance for energy storage and hybrid electric vehicles (HEV) (Tercero et al. 2015), (Graedel et al. 2015b). However, lithium batteries are more and more replacing such nickel batteries and most HEVs marketed today use Li-ion batteries (Harvey 2018), (ProSum 2019). There are no substitutes foreseen in the short to mid- term that can replace the role of lithium in rechargeable batteries for electric vehicles and energy storage systems. In the longer term, lithium batteries may even replace traditional lead-acid car batteries for starting, lighting and ignition (SLI), leading to much higher demand (Ferg, Schuldt, and Schmidt 2019).

In primary batteries, zinc is the main substitute to replace lithium as anode material in the cell (Graedel et al. 2015b), as well as calcium, magnesium, and mercury (Bradley et al. 2017).

"Batteries: Technology Development Report" [3] provides data on the current development of batteries for a range of uses. However, this is mainly an analysis of development projects so does not give a list of commercially available options at the current time.

LUBRICATING GREASES

Alternative formulations with polyurea, calcium and aluminium soaps, can substitute for lithium stearates in lubricating greases (Saruls 2017), (Bradley et al. 2017).

PRIMARY ALUMINIUM PRODUCTION

For primary production and continuous casting, sodium is a potential substitute (Graedel et al. 2015a).

ALUMINIUM ALLOYS

Composite materials consisting of boron, glass, or polymer fibres in engineering resins can be used in place of aluminium-lithium alloys (Bradley et al. 2017). Finally, no substitutes exist for the applications of pharmaceuticals and polymer production (Graedel et al. 2015b).

PHARMACEUTICAL PRODUCTS

The ongoing development of treatment for depression is summarised in National guidelines and new research continually, for example[4]. As well as pharmaceutical replacements, alternative therapies can also be used to minimise use (for example cognitive behaviour therapies, talking therapies etc.).

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[3] https://op.europa.eu/en/publication-detail/-/publication/55fe34e2-6b54-11eb-aeb5-01aa75ed71a1/language-en

[4] https://evidence.nihr.ac.uk/alert/the-most-effective-antidepressants-for-adults-revealed-in-major-review/

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OTHER APPLICATIONS

In electronics, lanthanum and gallium are substitutes for lithium tantalite in electronics used in surface acoustic wave filters for sensors (Tercero et al. 2015). In air conditioning and dehumidification systems, substitution with ammonia/water systems is possible but with reduced performance (Graedel et al. 2015b).

A summary of the substitutions given above are presented below:

Table 8. Uses and possible substitutes of lithium

Application	Share	Substitutes	Sub share	Cost	Performance
Glass and ceramics	55%	Potassium	25%	Similar or lower costs	Reduced
	55%	Sodium	25%	Similar or lower costs	Reduced
	55%	Aluminium	1%	Similar or lower costs	Reduced
	55%	Silicon	5%	Similar or lower costs	Reduced
Lubricating greases	24%	Calcium	10%	Similar or lower costs	Similar
	24%	Polyurea	6%	Slightly higher costs (up to 2 times)	Similar
	24%	Aluminium	4%	Similar or lower costs	Similar
Cement production	5%	not assessed, below 10%			No substitute
Pharmaceutical products	1%	not assessed, below 10%			No substitute
Rubber and plastics production	1%	not assessed, below 10%			No substitute
Al-Li alloys	2%	Al-Sc alloys	5%	Very high costs (more than 2 times)	Similar
	2%	No substitute	95%		No substitute
Batteries	12%	NiCd/NiMH	5%	Similar or lower costs	Reduced
	12%	Dual Carbon batteries	0%	Similar or lower costs	Similar
	12%	Sodium ion batteries	0%	Similar or lower costs	Similar
	12%	Zinc ion batteries	0%	Similar or lower costs	Similar
	12%	No substitute	95%		No substitute

- EU end use share, 2016 (MSA, 2020)

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LITHIUM SUPPLY

EU SUPPLY CHAIN

The lithium flows through the EU economy are shown in **Erreur ! Source du renvoi introuvable.** for year 2016. It is obvious that important changes occurred between 2016 and 2020 but no update is available for this MSA.

In 2020, the EU apparent consumption is about 1900 tonnes in lithium content.

Portugal produced about 400 tonnes of lithium content ores and concentrated but they were not refined in the EU. About 21 kt of lithium concentrates – mainly carbonates (with an average Li concentration around 18%) were annually imported in EU during the period 2016-2020. In 2020, the principal supplier of the EU for lithium carbonate is Chile (more than 80% of total EU sourcing) whereas lithium hydroxide and oxide are supplied from Russia and Switzerland for about 80%.. The end-of-life recycling input rate in EU is negligible (Eurostat, 2021).

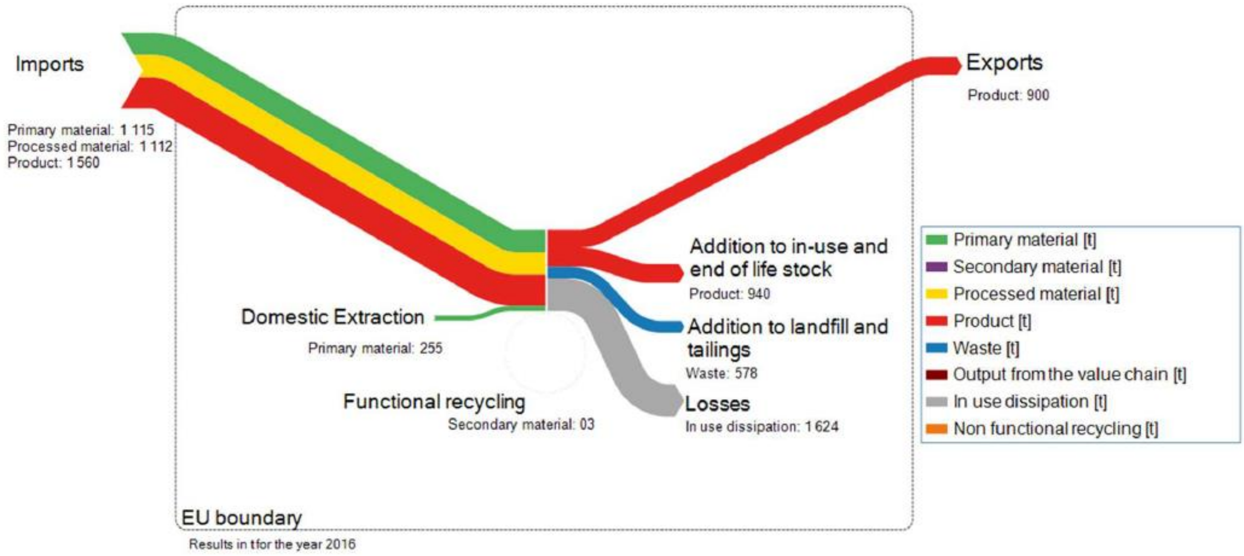

Figure 17. Simplified MSA of lithium flows in the EU. 2016 (MSA 2019)

No metallurgical processing of chemical-grade lithium concentrates is taking place in the EU. Downstream lithium compounds such as butyl-lithium, lithium chloride, and lithium metal are produced at Langelsheim in Germany by Albemarle from imported lithium carbonate (Albemarle 2019, USGS 2018).

The majority of end-uses of lithium are dissipative. Lithium is either not available for recycling at all, or extremely hard to be recovered. For example, recovery by lubricating greases and pharmaceuticals is impossible, while recovery by ceramics and glasses is not techno economically sustainable due to the high energy demand through the recycling process. The scientific community, is so far, mainly focused to Li recovery by end-of-life spent batteries but less than 1% of Li is recovered today (Bay, 2021). Umicore Battery Recycling has announced lithium recovery from the slag fraction of its pyrometallurgical process on an industrial level (Hagelüken 2018). Also, Recupyl in France patented a hydrometallurgical recycling process enabling Li recovery on an industrial scale (Lebedeva, Di Persio, and Boon-Brett 2017). Lastly, Duesenfeld applies a patented

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technology for recycling Li-ion batteries, developed within the frame of the research project Lithorec II, allowing lithium recovery of at least 85% combining mechanical processing with subsequent hydrometallurgical processing (Duesenfeld 2019). Recovery of lithium is planned at the Accurec facility in Germany after a planned investment in thermal deactivation and treatment of spent lithium batteries, which will make it one of the most significant lithium recycling locations globally (Recharge 2018). No information is available from other recycling facilities in the EU on current industrial-scale lithium recovery.

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF LITHIUM

GEOLOGICAL OCCURRENCE

Estimates for the average lithium content in the Earth's crust range from 16 to 20 ppm (BGS 2016) (Rudnick and Gao 2014), but lithium abundance ranges from about 30 ppm in igneous rocks to approximately 60 ppm in sedimentary rocks (Evans 2014). According to (Rudnick and Gao 2014), the abundance of lithium in the upper crust is 24 ppm. Lithium also occurs in various types of brines, as well as in seawater at an average concentration of 0.18 ppm (BGS 2016).

Because of its high reactivity, lithium does not occur in elemental form in nature, but in the form of compounds as silicates in igneous rocks, in some clay minerals and generally as chloride in brines (Evans 2014). There are more than 100 known minerals that may contain lithium, but few with enough lithium content to be economical to extract (BGS 2016). Two distinct deposit types are identified from which lithium can be extracted; brine deposits in which the average lithium grade is about 0.1% Li2O, and hard-rock deposits where lithium generally grades from 0.6 to 1.0% Li2O hosted by various Li-bearing minerals (Gautneb et al. 2019).

Continental brine deposits contain substantial lithium resources. These brines are formed in enclosed basins where inflowing surface and underground water with a medium content of dissolved solids from surrounding weathered rocks become mineral-rich due to evaporation on high ambient temperatures (Evans 2014). Economic Li deposits of brines mainly occur in areas where arid climate and high evaporation has resulted in further lithium enrichment (0.04-0.15% Li average grade) originating from weathered Li-bearing source rocks; these deposits are usually associated with salt lakes or salt pans (BGS 2016). Likewise, economically viable concentrations of lithium are found in geothermal and oilfield brines where lithium extraction has been demonstrated as a by- or co-product of existing operations, although not yet on a commercial scale (BGS 2016) (Bradley et al. 2017).

Brine resources are mostly found in South American countries – Chile, Argentina and Bolivia – in an area known as the "Lithium Triangle", which contains half of the world's lithium resources and 70% of global reserves at the end of 2018. Bolivia hosts the most abundant lithium brine resource in the world (Salar de Uyuni); however, it has not been exploited until 2016, but action has been undertaken in this direction. Currently, most lithium extraction from brines comes from the Salar de Atacama in Chile; other significant brine-based deposits are located at Salar del Hombre Muerto and Salar de Olaroz in Argentina. Brine operations in South

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America accounted for 55% of global lithium supply in 2016. Other brine deposits, though of generally lower grade, are located in the USA (e.g. Silver Peak) and China (e.g. Qinghai province).

Specific interest should be given on the potential recovery of lithium by geothermal waters in EU. The existence of geothermal fluids rich in Li in France and Italy has been described since the early 90es. Lithium concentration in these waters reach 0.04 mol/L (Pauwels et al. 2009). The respective technology for the extraction of Li from these fluids has been recently developed and it is subsequently described.

GLOBAL RESOURCES AND RESERVES:

Owing to continuing exploration, identified lithium reserves and resources have increased substantially worldwide with total about 22 and 89 million tonnes respectively in 2021. Other countries with reported reserves include Austria, Canada, Congo (Kinshasa), Czechia, Finland, Germany, Mali, Mexico, and Serbia.

Table 9. Lithium reserves and resources by country (USGS, 2022).

Country	Reserves of elemental lithium (million tonnes) USGS	Resources of elemental lithium (million tonnes) USGS
United States	0.75	9.1
Argentina	2.2	19
Australia	5.7	7.3
Brazil	0.095	0.47
Chile	9.2	9.8
China	1.5	5.1
Portugal	0.06	0.27
Zimbabwe	0.22	0.5
Bolivia		21
Other countries	2.7	16.5
Total	22	89

EU RESOURCES AND RESERVES

EXPLORATION AND NEW MINE DEVELOPMENT PROJECTS IN THE EU

Mineral exploration activities targeting lithium are in progress across the EU. The recent developments for projects having reached a more advanced stage are listed below:

Austria. At the Wolfsberg spodumene deposit, total lithium mineral reserves and resources reported in April 2018 under the JORC Code amount to 7.5 million tonnes (0.71% Li_2O average grade) and 11 million tonnes (1.00% Li_2O average grade) respectively. A pre-Feasibility study is completed. (European Lithium Ltd 2018);

Czechia. The Cinovec lithium-tin deposit consist the largest primary Li resource in Europe. It is expected to contain probable ore reserves of 34.5 Mt graded at 0.65% Li_2O and 0.09% Sn, while the indicated and inferred resources are estimated to be 695.9Mt, graded at 0.195% Li. The Cinovec locality is situated approximately 100km to the north-west of Czech Republic's capital Prague, on the side of German border. The deposit is associated with a granite structure cupola and comprises irregular metasomatic greisen, which hosts quartz,

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zinnwaldite, fluorite, and adularia-K feldspar. The mining method which proposed for the ore extraction is the long hole open stopping method. Lithium is mainly contained in mica phase. The Cinovec lithium-tin project is expected to provide 360,000 tonnes annually of mica concentrate to lithium carbonate and hydroxide plants. Pre-feasibility study for the Cinovec lithium-tin project was completed in April 2017. The results showed that the average rate of ore production will be 1.68 million tons per year for 21 years (nsenergybusiness, 2021)

Finland. JORC compliant estimates of total resources for spodumene deposits in pegmatites have been announced in February 2019 to be 9.5 million tonnes at 1.16% Li_2O average grade. Total reserves are estimated at 7.4 million tonnes at 1.04% Li_2O average grade. This figure is cumulative for six distinct deposits in the area, i.e. Syväjärvi, Rapasaari, Länttä, Outovesi, Emmes and Leviäkangas. During the second quarter of 2021, Keliber reported increased lithium ore resources by 2 million tonnes as result of a long-term exploration and resource drilling programme, therefore a total deposit of 13.7 million tonnes has been estimated (Keliber, 2021). The activating mining company in Keliber programs the annual producing of 15,000 metric tons (tonnes) per year of battery-grade lithium hydroxide from 625,000 tonnes of lithium-rich spodumene rock by the end of 2024. Rapasaari deposit also in Finland consists a second important deposit containing 8.1 million tonnes of lithium ore (C&en, 2021).;

Germany. Total lithium resources of the Zinnwald deposit reported under NI 43-101 requirements are approximately 40 million tonnes with an average concentration of 0.76 wt.% Li_2O, as of October 2018 (Deutsche Lithium GmbH 2018). Lithium mineralisation is represented by the zinnwaldite lithium mica. A feasibility study is concluded (May 2019) and mineral reserves account for 31.2 million tonnes at 0.65% Li_2O average grade (Deutsche Lithium GmbH 2018). In addition, an inferred lithium mineral resource of 25 million tonnes grading 0.45% Li_2O at the Sadisdorf project is announced (December 2017) based on re-analysis and re-interpretation of historical drilling data (Lithium Australia 2017); Last but not least, vast JORC-compliant lithium resources were announced in December 2019 to be contained in geothermal brines at the Vulcan lithium brine project in the Upper Rhine valley of Germany. Total inferred mineral resources are estimated to 2.484 million tonnes of lithium, at a lithium brine grade of 181 mg/l Li (Vulcan Energy Resources 2019; the recovery of both lithium and geothermal energy have been successfully tested by injecting brine deep underground following a carbon-neutral extraction process.

Portugal. According to information published in September 2017 by the Portuguese Lithium Working Group (Lithium Working Group, 2017) based on reports by operating mining companies, total resources in Portugal were estimated at approximately 30 million tonnes at an average grade of 0.81% Li_2O (Lithium Working Group, 2017). However, as exploration and mine development projects are in progress, JORC compliant lithium resources of the active projects are estimated at the end of 2018 to be about 43 million tonnes at an average grade of 0.88% Li2O. In particular:

- The latest (May 2019) JORC compliant update of the overall mineral resource estimate of the ongoing spodumene mine development project Mina Do Barroso in northern Portugal amounts to 27 million tonnes at 1.06% Li2O (Savannah Resources Plc 2019b). A Feasibility study is on track (Savannah Resources Plc 2019a); Savannah Resources Company has completed the environmental impact assessment of its plan to mine annually 175,000 tonnes of spodumene.

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- The JORC compliant mineral resource estimate for the ongoing exploration project in the Alvarrões lepidolite mine is 5.9 million tonnes at 0.87% Li_2O (April 2019). Advanced exploration by drilling has been completed (Lepidico Ltd 2019);
- Exploration is also underway in the Sepeda deposit. The last available (February 2017) JORC compliant mineral resource estimate is 10.3 million tonnes at 1.0% Li2O. A scoping study has been finalised (Dakota Minerals 2017);
- Exploration works are ongoing in the Argemela tin-lithium project (Patricia Alves Dias 2018). In 2012, JORC-compliant mineral resources were estimated to be 11.1 million tonnes grading 0.21% Li (PANNN2017).

Spain. The San Jose deposit, where lithium is hosted mainly in lithium-mica minerals, holds in total 111 million tonnes of JORC compliant estimated resources at an average grade of 0.61 % Li_2O average grade, as announced in May 2018. A Feasibility study is underway (Infinity Lithium Ltd 2018).

Serbia: A notable world-class lithium deposit was discovered by Rio Tinto in the Jadar Basin, Serbia. Lithium exists as jadarite, a new mineral species, having a chemical composition $LiNaSiB_3O_7(OH)$. According to the estimation of the company, the ore reserve has an amount of 16.6 Mtonnes at 1.81% Li_2O and 13.4% B_2O_3. The mineral resource of the locality comprises 55.2 Mtonnes of indicated amount at 1.68% Li_2O and 17.9% B_2O_3 with an additional 84.1 Mtonnes of inferred resource at 1.84% Li_2O and 12.6% B_2O_3 (Rio Tinto, 2020). The feasibility study for the exploitation of the deposit was completed since February 2020. The results of the drilling were incorporated into an update of the geological model. The implementation of the project includes an underground mine, an industrial processing facility and all associated infrastructure. The project aims to supply the markets with a significant amount of end-industrial products for lithium batteries for electric vehicles and energy storage facilities (me.smenet.org, 2020). Valjevo consists a second significant deposit in Serbia with a 200 million tons of lithium borate ore. Its mineralization is similar to the Jadar deposit. Both Li and B are concentrated in fluids derived from mineral springs or alteration of tuff beds. Through digenesis during burial, crystalline evaporite deposits formed and are stratigraphically associated with lacustrine sediments, air-fall tuffs, and travertine. According to exploration drillings, the average Li concentration of the ore is around 0.08 wt.% (Stantec, 2020). Manufacturers of materials for lithium-ion batteries, including BASF, negotiate for the collaboration with mining companies in Europe (C&en, 2021).

WORLD AND EU MINE PRODUCTION

From 2010 to 2020, the global production of lithium raised from 28,100 tonnes to 95,000 tonnes (lithium content, Statista 2021). Same level of information can be obtained from World Mining Data with a production in Li2O content increasing from 52,000 tonnes in 2008 to about 200,000 tonnes in 2018 (**Erreur ! Source du renvoi introuvable.**).

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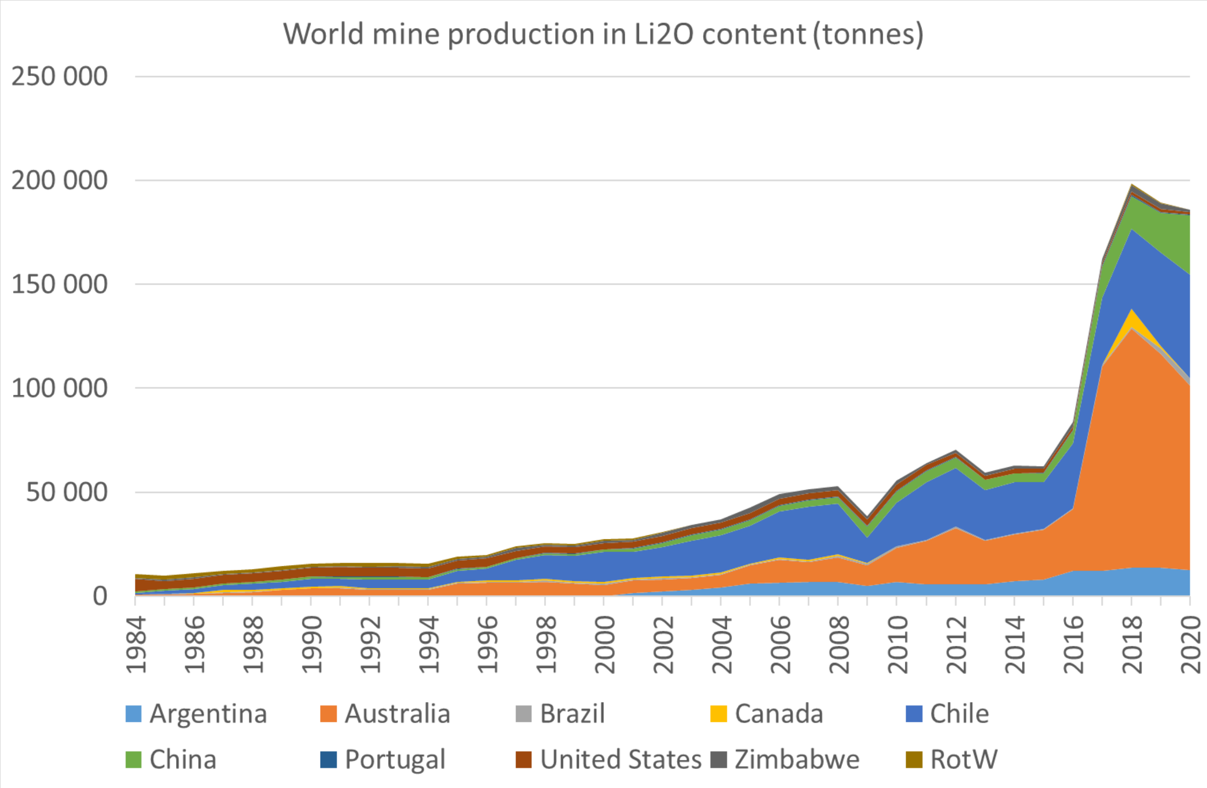

Figure 18. Global production of lithium, in Li2O content. (WMD, 2022)

In 2019, Lithium was currently extracted for more than 95% in Australia, Chile, China and Argentina. In Australia and China, lithium is mainly extracted from hard rocks, whereas in Chile, and Argentina, lithium is extracted from brines (BGS, 2016) (Figure 19). The produced amounts of lithium by country can be seen in Table 8. In 2015, around 50% of lithium supply came from lithium brines, approximately 45% from hard-rock spodumene ores, while other lithium minerals accounted for 5 to 10% (Hocking et al. 2016).

Lithium is currently extracted in Portugal in the form of lepidolite and marketed as Li-rich feldspars used by the ceramics industry. Six mining sites were registered as active in 2017 at the Guarda (Alvarrões), Braga (Gondiães) and Villa Real (Alijó, Lousas, Mina do Barosso) districts (Dinis P. and Horgan S 2018). The annual production over 2012-2016 averaged to about 24,000 tonnes of lepidolite minerals (BGS 2019) giving 240 tonnes of Li2O content (WMD). Since 2011, production from Spain is not included in statistics published by common sources such as the World Mining Data, British Geological Survey's World Mineral Statistics, or the United States Geological Survey. However, there are reports that Li-containing minerals were extracted in Spain at about 8 ktonnes tonnes per year of gross weight in the 2011-2014 period for use in the ceramics industry (Regueiro y González-Barros 2016), while the French Geological Survey reports a small production of lepidolite concentrates in Spain of 100 tonnes in LCE content in 2015 (BRGM 2017). In addition, small quantities of lithium are produced in the form of Li-rich mica concentrates as a co-product of kaolin mining at Échassières, France for use in the glass industry, but production is also not published by mine statistics providers. The estimated output in 2015 was 15 ktonnes of concentrates at a grade of 1.8% of Li_2O (BRGM 2017).

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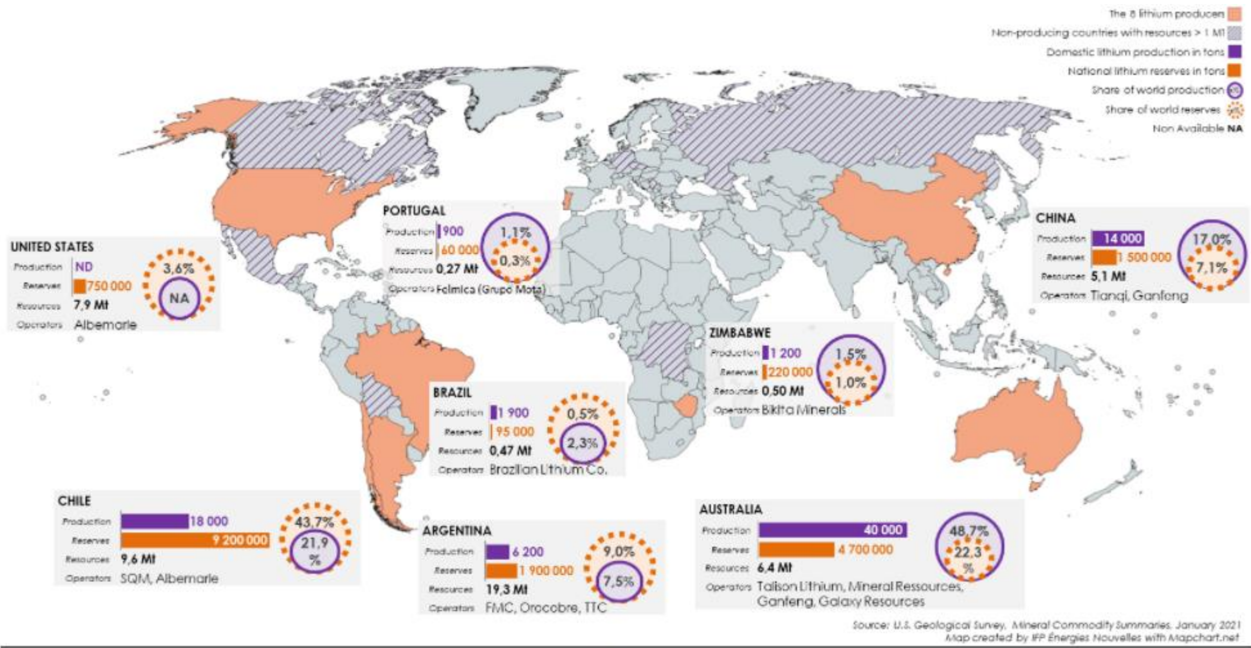

Cart 1
Source: USGS, 2021

Figure 19 .Global lithium production and reserves in 2020 in tonnes (IFPEN 2021)

Table 10. Lithium mine production in 2021 (WMD 2022 and USGS, 2022).

Country	*Li_2O 2021 production (thousand tonnes) WMD*	*Elemental Li production in 2021 (thousand tonnes) USGS*
United States	1.2	-
Argentina	12.6	6.2
Australia	88.5	55
Brazil	3.7	1.5
Canada	0	-
Chile	49.3	26
China	28.8	14
Portugal	0.28	0.9
Zimbabwe	0.86	1.2
Other countries	0.08	-
Total	185.9	100

In the EU, about 900 tonnes of lithium were extracted in 2020 in Portugal in the form of lithium carbonate, which is used exclusively in the ceramics industry (Carvalho and Farinha, 2004).

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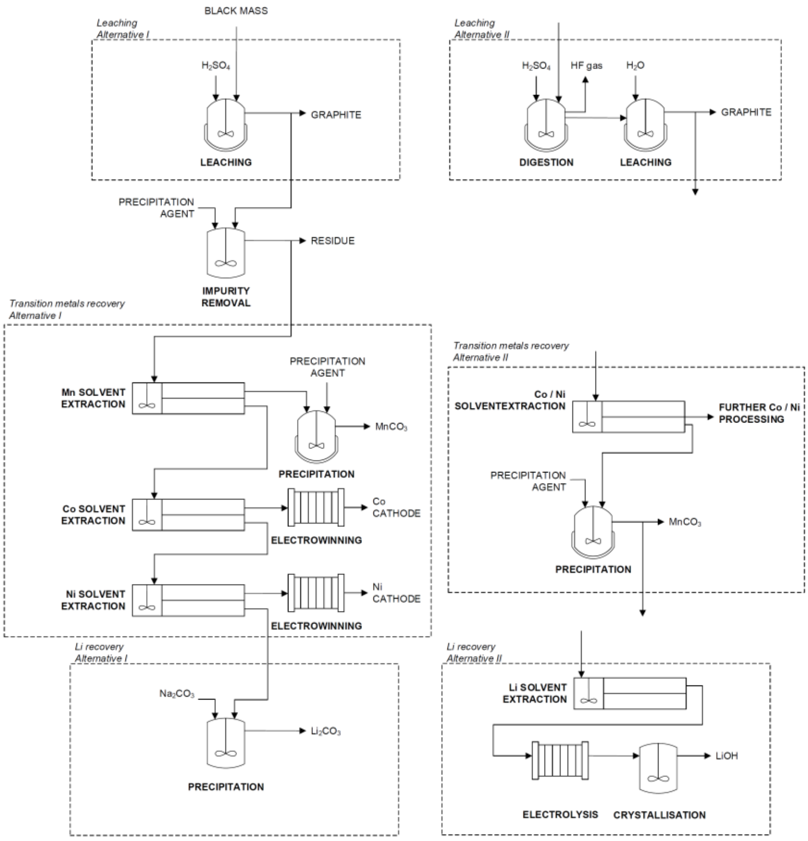

Figure 20. Flow sheet of the hydrometallurgical processing for the recovery of Ni, Co and Li by black mass (Brückner et al. 2020; Haga et al. 2019; Hanisch et al. 2019; Lipp, 2017)

Batteries could be the main (/only?) source of recycled lithium, but its recovery is still a challenge in 2021 due to high energy consumption. Cobalt and nickel remain the two target metals and the main value carriers though the recycling process. Lithium recovery is expected to be economic feasible during the next decade due to the capacity increase of the recycling plants. The production of Li_2CO_3 and LiOH end-products from the black mass (i.e. the scrap fraction material of electrodes after the mechanical removal of Al and Cu) through hydrometallurgy is the most possible commercial recycling scenario. Currently, lithium presents a high revenue distribution (≈32%) of Li-ion batteries black mass.

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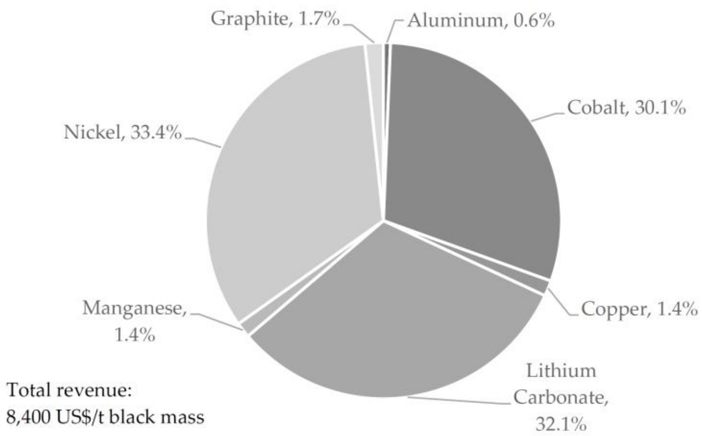

Figure 21. Estimated revenue distribution of Li-ion batteries black mass (Brückner et al. 2020).

PROCESSING

In 2017, around 65% of produced lithium originated from continental brines. Approximately 60% of this comes from the salt flats of Chile, as well as 20% and 14%, from China and Argentina, respectively. The main processes for recovering lithium from brines are called the lime soda evaporation process and generally consists of stages starting with concentration by evaporation, impurity removal, and precipitation by carbonation. Lithium production from brine presents about a 30–50% a lower operating cost in comparison to the respective extraction from hard-rock sources (Meng et al. 2019) (Erreur ! Source du renvoi introuvable.).

Approximately 35% of the world's supply of lithium products is sourced from ores and clays, most of which (85%) is extracted from the Greenbushes deposit in Western Australia. Spodumene accounts for approximately 90% of global non-brine lithium carbonate equivalent production. The process of LiOH and Li_2CO_3 production by spondumene and clays, respectively is complex and comprises various steps of beneficiation, pre-leaching preparation (i.e. roasting), leaching and purification (**Erreur ! Source du renvoi introuvable.**) (Meng et al. 2019). General flowsheet for the production of lithium carbonate from continental salt brines (Meng et al. 2019).

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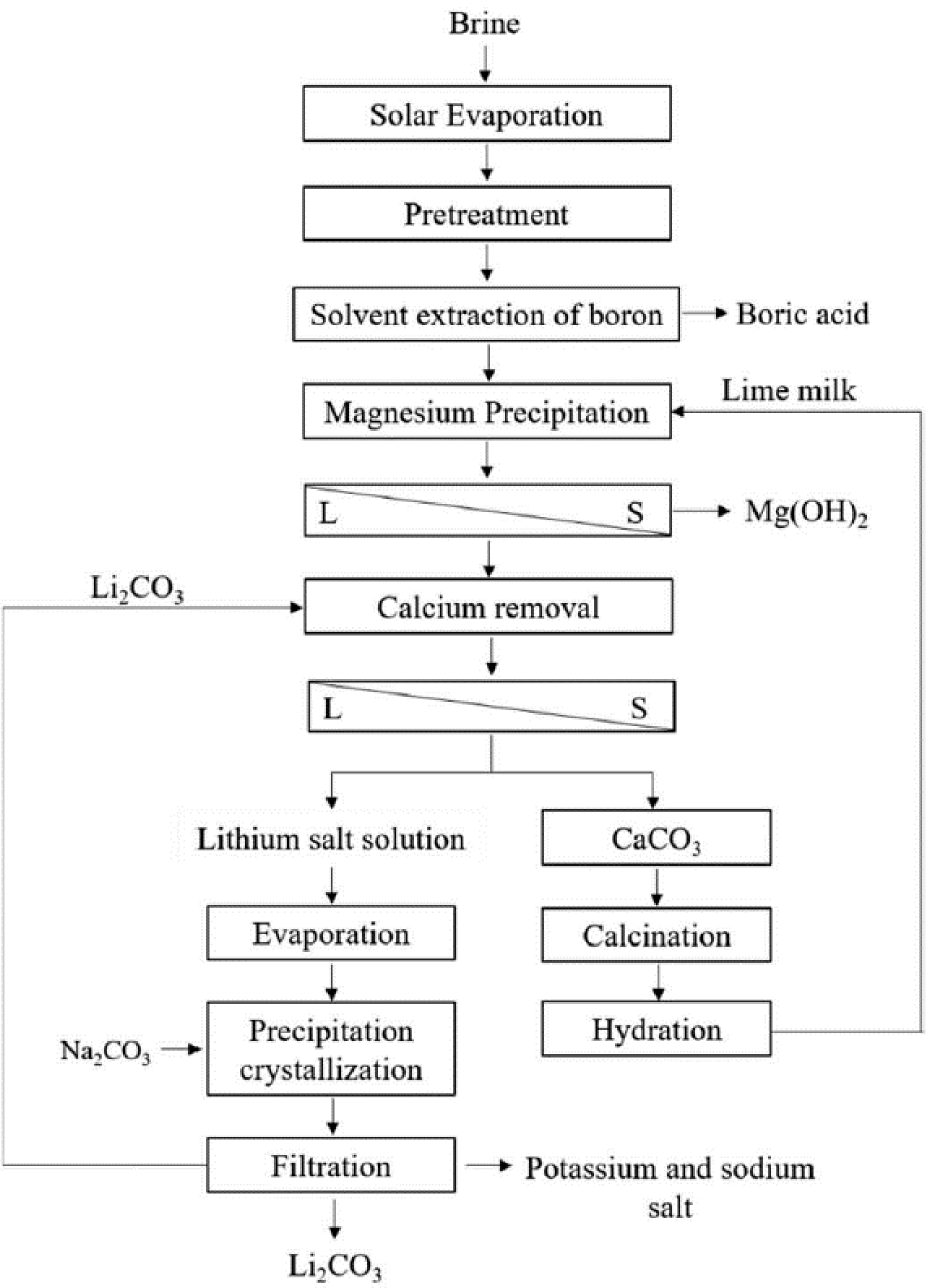

Figure 22 .General flowsheet for the production of lithium carbonate from continental salt brines (Meng et al. 2019).

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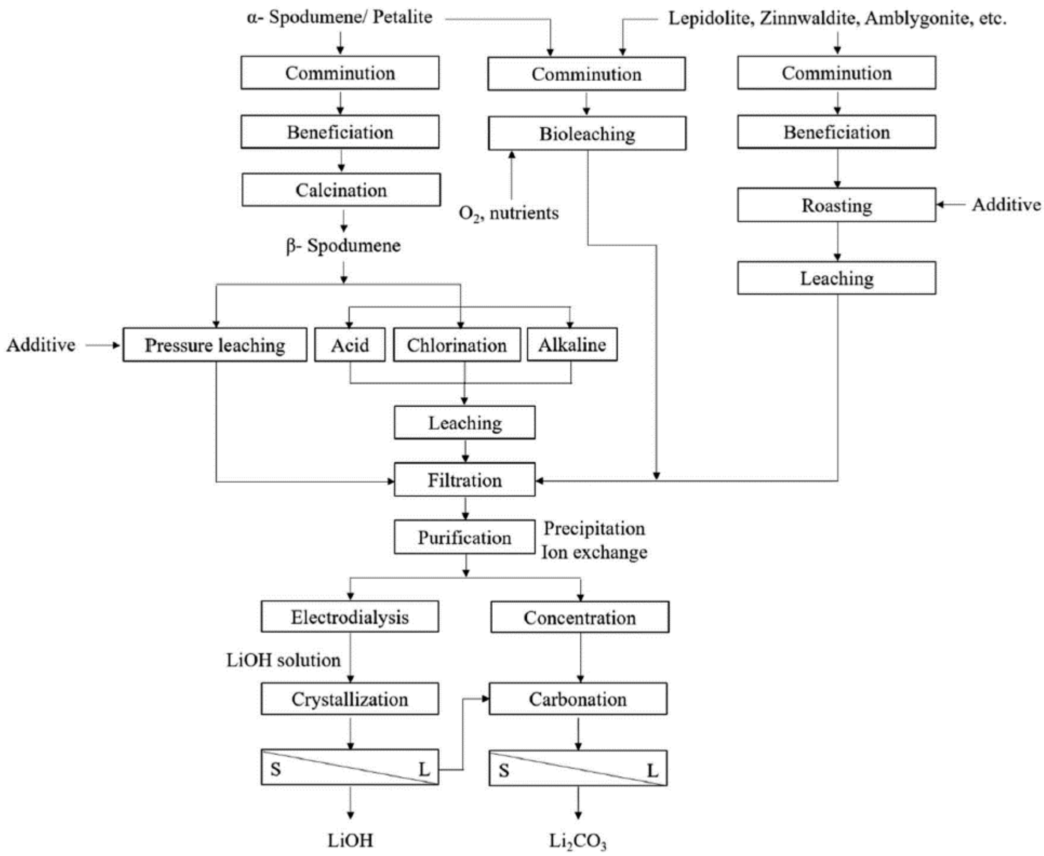

Figure 23. General flowsheet for the production of lithium carbonate and lithium hydroxide from Mineral ores and clays (Meng et al. 2019).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Lithium has long been used as a relevant treatment for bipolar disorder (Mitchell and Hadzi-Pavlovic, 2000). Yet altered functioning of thyroid function has been observed as a result to exposure to lithium via drinking water and other environmental sources, in line with known side effects of medical treatment with lithium (Broberg et al., 2011).

On 4 December 2019, the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) submitted a proposal to the European Chemicals Agency (ECHA) for harmonised classification of lithium carbonate, lithium chloride and lithium hydroxide under the CLP Regulation (Classification, Labelling and Packaging of products), stating that "these three salts are hazardous to fertility and foetal development" (ANSES, 2020).

Lithium is classically not extracted from artisanal mining nor associated with Acid Mine Drainage (German Environment Agency, 2020). Moreover, it is extracted from deposits with a limited association of other heavy metals (German Environment Agency, 2020).

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The use/ban of lithium is restricted under REACH Regulation (EC) No 1907/2006 Annex XVII (Deutsche Forschungsgemeinschaft and Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, 2002). In REACH Regulation (EC) No 1907/2006 Annex XVII, Point 40 states that the substance shall not be used, as a substance or as mixtures in aerosol dispensers where these aerosol dispensers are intended for supply to the general public for entertainment and decorative purposes. In addition, Directive 2012/18 states that this substance is subjected to the hazard categories of the Hazardous Incident Ordinance "Substances or mixtures with hazard statement EUH014".

ENVIRONMENTAL ISSUES

A number of Life Cycle Assessment (LCA) studies of lithium production have been performed in the recent past. The LCA of $LiOH.H_2O$ production from brine and ore, led by the consultancy Minviro, indicates that the CO_2 emissions from $LiOH.H_2O$ production range from 5.0 tonnes per tonne of $LiOH.H_2O$ (case of Chilean brine) to 14.8 tonnes of CO_2 per tonne of $LiOH.H_2O$ (Australian source of spodumene, processed in China; Grant et al., 2020). These results are in reasonable alignment with those of Kelly et al. (2021), who calculate a greenhouse gas footprint of 6.9 - 7.3 tonnes CO_2-eq/tonne $LiOH$-H_2O from lithium extracted from brine, and of 15.7 tonnes CO_2-eq/tonne $LiOH.H_2O$ for lithium extracted from ore processed in Australia with $LiOH.H_2O$ production in China.

Grant et al. (2020) conclude that the CO_2 intensity of processing spodumene concentrate in China is the highest in the world. This implies that $LiOH.H_2O$ products from China are the most CO_2 intense ones. Process energy inputs account for a significant portion of the greenhouse gas emissions from the production of brine- and ore-based lithium chemicals (Kelly et al., 2021; Grant et al., 2020).

Moreover, "water" (here referring to the availability of freshwater and the competition that can arise between the mining industry and other water users to access freshwater) stands for a high risk regarding lithium exploitation (Lèbre et al., 2020), still with differences depending on the production routes. The production of Li_2CO_3 from brine-based resources implies less life cycle freshwater consumption per tonne of Li_2CO_3 than production from ore-based resources (Kelly et al., 2021). In the Andean region of Chile, Bolivia and Argentina, lithium extraction requires a relatively large amount of groundwater in one of the driest desert regions in the world to pump out brines from drilled wells (UNCTAD, 2021). This in particular implies that, considering a 2 MWh Lithium-ion battery storage, Chilean lithium mining holds the largest share of the total corresponding quantitative, life cycle wide, Water Scarcity Footprint (comprising physically used water; Schomberg et al., 2021).

Finally, on the contrary, issues of land use (referring to presence of competing land uses and associated livelihoods including agriculture and forestry), conservation (proximity to key biodiversity hotspots), and waste (climatic, topographic and tectonic factors that play a role in mine waste containment) are of lower concern regarding lithium production (Lèbre et al., 2020).

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NORMATIVE REQUIREMENTS RELATED TO THE USE AND PROCESSING OF LITHIUM

Technical rules for the use of Lithium can be found in the GESTIS Substance database[5]. In addition, lithium is included under the German regulation of accident insurers[6] for the use of respiratory protective equipment. International limit values for lithium and compounds[7], lithium fluoride[7], lithium hydroxide[7] and lithium hydroxide monohydrate [7] can be found in the GESTIS international limit values database.

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF LITHIUM FOR EXPORTING COUNTRIES

According to WMD (Federal Ministry Republic of Austria, 2022), in 2019 Lithium is mainly produced in Australia (103.000 tonnes), Chile (47.770 tonnes) and Argentina (13.670 tonnes). In 2021, lithium is mainly produced in Australia (55,000 tonnes), Chile (26,000 tonnes), China (14,000 tonnes) and Argentina (6,200 tonnes). Mostly, the mineral spodumene is extracted in Australian open pit and underground mining operations (Öko-Institut, 2020). Four mineral operations in Australia, two brine operations each in Argentina and Chile, and two brine and one mineral operation in China accounted for the majority of world lithium production (USGS, 2022). More than 40% of today's lithium production comes from hard rock mining. The global demand for lithium has generated a series of policy responses in different countries in the southern cone triangle (Argentina, Bolivia and Chile), which together hold around **80% of the world's lithium salt brine reserves** in their salt flats in the Puna area (Marchegiani, et al. 2019). The Atacama Desert both in Chile and across the border in Bolivia and Argentina contains 70% of the world's supply (Valentino, 2021).

Chiles's largest producer, **Sociedad Química y Minera de Chile** S.A. (Soquimich / SQM, former state owned company), is one of the world's largest lithium producers (and the world's largest producer of potassium nitrate and iodine). SCM produces lithium carbonate and lithium hydroxide near the city of Antofagasta, Chile, from the solutions brought from the Salar de Atacama (SQM, 2021). In 2021, SQM had **6081 employees** (Statista, 2022). Chilean miner SQM reported in March 2022 a near twelve-fold rise in quarterly profit as it benefited from higher prices of the metal used in electric-vehicle batteries. Net profit rose to $796 million in the first quarter ended March 2022, while **revenue** nearly quadrupled to **$2.02 billion** (Reuters, 2022). SQM products are sold in approximately 110 countries through its worldwide distribution network, with 91% of SQM's sales in 2020 derived from countries outside Chile. In 2020, SQM had revenues of US$1.817 million, gross profit of US$482.9 million and profit attributable to controlling interests of US$164 million. SQM's worldwide market capitalization in 2020 was approximately **US$11.0 billion** (SQM, 2021).

Argentina's lithium resources are vital to its economy and the global supply chain. Its lithium production accounts for 16% of the overall global lithium production. However, Argentina's mining industry only accounts for 0.6% of the Gross Domestic Product (GDP) while the government hopes to increase its contribution to at least 3% in the coming years. Although Argentina has been extracting lithium since 1997, for a long time there

[5] See https://gestis-database.dguv.de/data?name=008010
[6]See https://publikationen.dguv.de/regelwerk/dguv-regeln/1011/benutzung-von-atemschutzgeraeten
[7] See https://limitvalue.ifa.dguv.de/WebForm_ueliste2.aspx

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was only one lithium-producing project in the country. In recent years, Argentina has experienced increased interest in lithium mining activities. In 2016, it was the most dynamic lithium producing country in the world, increasing production from 11% to 16% of the global market. There are now around **46 different projects of lithium extraction at different stages** (Telam, 2017). In this way, the Argentine mining industry is expanding lithium production. In March 2022 South Korean steel company Posco announced that it will start a new project to mine lithium in Argentina. This will add to the economic boost that lithium has given South Korea. Posco will invest US$4 billion in lithium mining in Argentina, a move that will prove economically beneficial for South Korea, Argentina and all workers involved in the new project. Posco and its employees will benefit from the new partnership with Argentina. It could inspire other countries to create new partnerships as they realize the competition in the lithium trade and lithium-ion battery creation (Mulvihill, 2022).

According to WITS (2022) the **top exporters of lithium** oxide and hydroxide in **2019** are China ($623.392K [49.282.800 Kg]), Chile ($120.240K [8.582.770 Kg]) and United States ($105.502K [9,361,740 Kg]). With regards to the total exports of the respective countries, the lithium export market of China represented about 0,02% of the total export; 0,2% of Chile's exports and 0,006% for USA.

According to OEC (2022) the top exporters of lithium carbonates in **2020** are Chile ($676M), Argentina ($127M), China ($60.4M), Belgium ($31.6M), and Netherlands ($31M). With regards to the total exports of the respective countries, the germanium export market of Chile represented about 1% of the total export; 0.2% of Argentina's export and 0.02% for China.

Table 11: Part of the vanadium market in main producers' economy in 2019 (source: UN [COMTRADE], 2020; WITS, 2022 [COMTRADE])

	total exports in US$	lithium exports in US$	Amount in kg	share
China	2494 bln	623.392,000	49.282.800	0,0249%
Chile	69.7 bln	120.240,000	8.582.770	0,1725%
USA	1644.3 bln	105.502,000	9.361.740	0,00641%

Table 12: Part of the lithium market in main producers' economy in 2020 (source: UN [COMTRADE], 2022; OEC, 2022)

	total exports in US$	lithium exports in US$	share
Chile	69.7 bln	676.000.000	0,9698%
Argentina	65.1 bln	127.000.000	0,1950%
China	2590.6 bln	600.000.000	0,0231%

In 2020, almost **three-fifths of the world's processed lithium exports came from South America**, with most of this volume sourced in Chile and Argentina (Valentino, 2021).

For the Chilean government, the incentives are obvious. According to the Ministry of Mines, Chile generates US$900 million annually from its lithium industry (S&P Global, 2021). **Lithium Chile accounts for almost 10% of GDP**, **almost half of exports and one third of foreign direct investment**. The lithium production industry in Chile continues to expand rapidly, with the intention to develop a downstream industry focused on the development of value-added products (Valentino, 2021). However, actually **Chile still lacks the industry to process** the raw material to generate higher revenues for the country. In that way, a more ambitious and

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future-oriented state policy would be needed (IGU, 2022). At the other side, the Chilean government is making a play to expand its influence on the global lithium market and bring more money into public coffers by inviting more companies to exploit its substantial lithium reserves. **Chile announced planned to greenlight auctions** for five new lithium developments, each with a quota for 80,000 tonnes of lithium metal equivalent annually, potentially unlocking lithium reserves beyond the country's largest salar, or salt flat. The new projects, which could take a decade to get into production, could contribute as much as 100,000 tonnes of lithium carbonate equivalent to the global market annually, increasing Chile's production by 71% above 2021 forecast levels (S&P Global, 2021). However, the announcement was cancelled due to protests of indigenous people and others (see below, section social and ethical aspects).

Investment in the lithium sector in Argentina over the last three years has surpassed **US$1.1 billion, while jobs created have tripled**, according to government data (Buenos Airies Times, 2021). The Alberto Fernández administration is determined to further develop **Argentina's lithium industry**, in teamwork with the nation's provincial governments and private investors, officials say. A growing and potentially pandemic-proof sector, there are currently 21 projects online with the capacity to extract 93 million tons at an annual rate of 350,000 tons. According to data from the Productive Development Ministry's Mining Secretariat, Argentina has two lithium mines in operation, one in construction and 17 advanced projects with the 10 largest accounting for 86 percent of the resources identified so far (Buenos Airies Times, 2021). Between 2017 and 2020 the accumulated investments in the lithium sector have totalled US$1.118 billion and employment has doubled in the last three years to register **1,474 direct jobs and almost 3,000 indirect by mid-2020**. The government considers that the local lithium investment projects could represent a relevant contribution to the northern provinces of Catamarca, Jujuy and Salta housing these resources, especially in the zones of the salt flats. These carry an important weight in the **export structure** of these regions, especially in the case of Jujuy, and could increase appreciably in all three provinces when the projects currently underway come on stream. In this sense Argentina is pushing forward this strategic sector for the long-term growth of the economy and the development of an ambitious lithium industry (Buenos Airies Times, 2021).

SOCIAL AND ETHICAL ASPECTS

Although Chile has the world's largest reserves of lithium, lithium extraction is linked to environmental, social and labour abuses, raising concerns that in the absence of sustainable industrial policies increased production could have (further) negative **impacts on local communities, workers and the environment**.

Mining at the Atacama salt lake poses social and ethical issues to which the indigenous peoples of the region in particular are exposed. And in fact, if the lithium production shall be extended, people in Chile started to **protest that the revenues received from lithium extraction should be primarily for the country's people**. The reason for the protest: In 2018, Chile granted the private mining company SQM, formerly Soquimich, permission **to mine lithium until 2030**. SQM is the largest lithium producer in the world, alongside the US Corporation Albemarle. Once a state-owned company, it was privatised during the military dictatorship under Pinochet in the 1980s. Since then, it has been in the hands of the Pinochet family. In recent years, Soquimich has been investigated several times for money laundering, tax evasion and illegal campaign financing (Boddenberg, 2018). In 2022 many sectors and people protested again, against the decision of the government to push ahead with its controversial lithium tender initiated in 2021 (see above). A tender process by awarding

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20-year contracts to two companies, the Chinese car and battery maker BYD and Chilean company Servicios y Operaciones Mineras del Norte S.A. belonging to the Errázuriz conglomerate. The **41 million dollar contracts** were intended to permit the extraction of 160,000 tons of lithium. However, a local court **suspended** the process following an appeal filed by the regional government and indigenous (IGU, 2022). This bidding process was inappropriate and improvised. It was based on an extractivist model that fails to protect the environment, workers, and communities or to generate value. Till now Chile has exported its lithium with little or **no added value**, denying the opportunity to generate higher revenues for the country (IGU, 2022).

Furthermore, **environmental, health, safety risks related to lithium in brines** are comparatively higher than for other sources of lithium, but particularly, the health and social effects are currently poorly understood. Of most concern is the fact that the mining practice uses evaporation ponds, exposing the products to the elements (e.g. wind and storms). Since geochemically lithium is a highly mobile element, lithium can be easily released into the environment and potentially **affect nearby communities** (Figueroa et al 2013). The processing of lithium mining involves evaporation of brines and washing the mineral with sodium carbonate in large-scale polyvinyl chloride (PVC)-lined shallow ponds. A failure in of PVC barriers may leak chemical substances such as softeners into the environment and cause water pollution (Wanger 2011). The consequences for human health and native biodiversity may be severe, although ingested lithium is not expected to bioaccumulate. However, a concentration of lithium in blood greater than 20 mg l^{-1} poses a risk of death (Agusdinata et al. 2018).

Indigenous people in Chile and across South America have been protesting against exploitative mining practices as well as the **over-exploitation of water** (Carrasco, 2019). Fundamentally, **Chile's lithium problems need to be understood geologically**. Lithium is typically found in saltwater brines, hidden under vast flats in the country's far north. To access the lithium, mining companies first extract the brine with pumps, then direct it to large pools. As the sun beats down on these pools over several months, the water evaporates. That leaves behind a mix of lithium and waste products. Cheap and effective, this technique has helped the Atacama's lithium industry explode. From just **20km² in 1997, the area being exploited has quadrupled** (VALENTINO, 2021). Brine only contains 0.15% lithium – meaning mining companies have to extract vast amounts of water to make ends meet. However, **95% of the extracted water is lost to evaporation** forever. In a region where it only rains about 15mm a year, many locals are concerned about the effects extraction can have on other water sources. **Surrounding communities** typically view these deposits as water resources. When they are extracted, linked freshwater aquifers in surrounding areas are drawn down, making it more difficult for communities to access water for their own purposes. Some Atacamans are increasingly complaining about not being able to grow their staple peas and potatoes, or make money extracting salt, which also needs water (VALENTINO, 2021).

Though **companies like Albemarle and SQM** have invested in local communities, repairing schools and offering jobs, both have been accused of extracting **more than their legal quota** of salt water. In 2019, a court upheld a complaint that SQM was over-extracting brine. Certainly, the status quo is unsustainable (VALENTINO, 2021). Though the government technically owns the brine, it gives private companies like Albemarle and SQM a licence to control their own lithium operations. If, however, the **brine was not classified as mineral and reclassified as water** under the new constitution, it would give power to the indigenous people of the Atacama. All this is shadowed, momentum has been growing for impartial certification schemes that can guarantee responsible mining activities to international standards. A good example, is the Initiative for

Responsible Mining Assurance, which now helps SQM prove it's dealing fairly with local people (VALENTINO, 2021).

Little consideration has been given to the local impacts of lithium extraction in **Argentina considering human rights and the social** and environmental sustainability of the projects. Community members highlighted the significant impact of lithium mining projects on water resources and the **lack of information** on this matter, both from the companies and the State. In a study conducted by Marchegiani et al. in 2018, community members described the engagement process and relationship with companies wanting to extract lithium as more of a one-sided communication rather than a two-way process in which both sides could freely express their opinions to reach mutual understanding. The processes described did not seem to have involved communities or receive information about proposed projects and their impacts. For instance, **85% of the interviewees said they were not consulted** about how they wanted to receive information provided by the companies (Marchegiani et al, 2019).

To make sure local communities are informed, **companies are obliged to provide information in a suitable timeframe** and in a way that community members can understand. However, for community members it is difficult to understand the sort of information provided by the mining companies. This illustrates how companies retained complete control over what information was shared with communities. Also, it seems that companies did not fully disclose all the relevant information about foreseeable risk factors and their potential social and environmental impacts. This raises concerns about whether companies have acted in good faith (Marchegiani et al, 2019).

Moreover, it seems, that the provincial government did not gather any baseline information to understand the social and environmental impacts of lithium extraction in the concerned areas. In addition, this adversely **affects its capacity to evaluate the EIA** of the mining companies and to **monitor** its activities, further illustrating how companies have control over what information is available to communities and what is submitted in the EIA procedure. The State has a responsibility for implementing the EIA process to **guarantee participation rights** –a responsibility that cannot be transferred or delegated to a third party. However, Marchegiani et al identified the **absence of State representatives** throughout the engagement process. This has allowed companies to negotiate with communities in an asymmetrical power dynamic: terms and conditions to achieve their consent and social legitimacy were exchanged without any supervision by the State. This absence of State and lack of information both serve to cast doubt over how much the State knows about the companies' compliance with EIA requirements and their social and environmental impacts (Marchegiani et al, 2019).

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

a. R&D trends in terms of emerging LCGT

No data is available.

b. R&D trends in terms of emerging application of RM in already existing LCGT

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Optoelectronics

Li is fundamental for photorefractive crystals as a chemical component of $LiNbO_3$, which shows high quality and low cost. Furthermore, $LiNbO_3$ is considered an excellent substrate for linear and non-linear optical devices with application in data storage, showing high capacities and speed (Zhu et al., 2018; Caixia et al., 2005; Guo et al., 2004). Li allows obtaining extremely high technological performances using devices with lower material consumption due to their reduced dimension (Zhu et al., 2018; Caixia et al., 2005; Guo et al., 2004).

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Lithium-ion battery with silicon anode, nickel-rich cathode and in-cell sensor for electric vehicles[8]

This project aims at enabling next-generation lithium-ion batteries with a silicon-graphite composite anode and a nickel-rich NMC cathode to reach 750 Wh/L.

- A multi-sited and transnational study of transitions towards post-fossil fuel societies[9]

The overall aim of the project is to clarify how planetary strategies to decarbonize transport act upon the landscapes and societies where a) lithium is extracted, b) turned into technology and c) used and potentially reused and recycled? In addition, how can the different ways in which these strategies take place to inform non-destructive approaches to collaborative responsible actions to phase out fossil fuels—or decrease their utilization.

- Solvometallurgy for battery-grade refining of lithium (SOLVOLi)[10]

The project aims to develop the Proof of Concept for a disruptive, solvometallurgical flowsheet for the production, via LiCl, of LiOH. As this flowsheet allows to bypass the Li2CO3 step, SOLVOLi lowers the overall water, energy, CO2 and reagent footprint of LiOH production. Apart from validating and pre-demonstrating the novel flowsheet, SOLVOLi comprises a thorough IPR and upscaling strategy, in close collaboration with EU-based companies.

- A first step towards aviation decarbonization with smart lithium batteries[11]

The aim is to accelerate the market launch of its 28V lithium battery range, enabling it to address the largest aeronautic battery market, replace toxic batteries, and generate savings of 1M tons of Co2 within the next 8 years.

- Nanoscale phase evolution in lithium-sulfur batteries[12]

NanoEvolution aims to i) identify nanoscale structure-transport-performance correlations, ii) understand capacity limitations and reaction mechanisms, and iii) derive design criteria for improved Li-S battery performance. To achieve these goals, structure-sensitive in situ scattering and imaging methods during

[8] See https://cordis.europa.eu/project/id/875548
[9] See https://cordis.europa.eu/project/id/853133
[10] See https://cordis.europa.eu/project/id/963281
[11] See https://cordis.europa.eu/project/id/101009983
[12] See https://cordis.europa.eu/project/id/894042

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electrochemically operating custom-built in situ Li-S cells will be implemented. Specifically, in situ small and wide angle X-ray scattering (SWAXS) will be established and synergistically combined with nanoscale phase evolution modelling for data analysis. In situ nanoscale X-ray tomography will be realized to achieve continuous structural sensitivity from (sub-)nanometre (SWAXS) to sub-micrometre scales (tomography).

- All Solid-sTate Reliable BATtery for 2025[13]

The project will comply with improved safety demands and industrial standards by developing materials for a solid hybrid electrolyte and electrodes enabling high energy, high voltage and reliable all-solid-state Li-ion cells, Gen#2D cell design by processing techniques compatible with existing routes of large-scale cell manufacturing (10Ah, Energy type) and validation of a pilot prototype in a relevant industrial environment. In addition, develop a 2030s eco-designed generation for Power-type and Energy type all-solid-state cells in pre-prototype, define an efficient cell architecture to comply with improved safety demands and structure the whole value chain of the all-solid-state battery, including eco-design, end life and recycling.

- Ecologically and Economically viable Production and Recycling of Lithium-Ion Batteries[14]

The aim of the project is to improve the cycle-related costs per energy. An extended LCA, cradle-to-grave will also be set up to judge the environmental impact of the different options and to choose the best.

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[13] See https://cordis.europa.eu/project/id/875029

[14] See https://cordis.europa.eu/project/id/875514

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