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Raw Material Risk Assessment – Lithium

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Summary

With its Raw Material Risk Assessments, the German Mineral Resources Agency (DERA) at the Federal Institute for Geosciences and Natural Resources (BGR) aims to support German businesses in identifying potential price and supply risks on the commodity markets early, in order to develop, where necessary, suitable alternative procurement strategies.

This Raw Material Risk Assessment is an update of the 2017 study. In addition to looking at the current supply situation, it provides a detailed analysis of the supply risks for lithium until **2030**.

Over the past five years, developments on the lithium market have again gained considerable momentum. Reasons are the huge expectations of e-mobility and the demand this generates. Some countries are planning to discontinue both the manufacture and sale of traditional ICEs in the medium term. In June 2022, the EU passed a resolution to ban all new registrations of ICE vehicles from 2035. Although the production of lithium-ion batteries was an exclusively Asian domain until a few years ago, the United States and especially Europe are evolving into battery manufacturing hotspots. This is why issues concerning the availability, sustainable extraction and future price trends of battery raw materials such as lithium have come into focus. The results of this study show that the availability of battery-grade lithium could become a limiting factor for the global mobility transition.

Because of its specific properties, lithium is, and will continue to be in the next decades, a key component of rechargeable batteries that cannot be replaced, irrespective of the cathode chemistry used. By 2030, total demand for lithium will therefore grow by a factor of four to eight depending on the scenario.

Lithium price trends show that, already in the past, there have been large price fluctuations and brief price peaks. High price volatilities represent a particular procurement risk for businesses that is impossible to quantify. Since the start of 2022, the price level has been unprecedented. Lithium carbonate (> US$70,000/t), lithium hydroxide (> US$70,000/t) and spodumene concentrate (> US$5,500/t) are at an absolute all-time high.

The primary extraction of lithium is still oligopolistic, with supply currently dominated by two countries. In 2020, Australia and Chile together accounted for almost 75 % of global mining output. This situation is going to change by 2030. If projects are implemented successfully, especially Argentina, Canada, the United States, the DR Congo, Mali and Brazil could acquire considerable market shares. Australia's share of the lithium market could drop to around 37 – 43 %, and Chile's share might decline from 26 % at present to below 13 % by 2030 because of the complex, historically grown structure of the Chilean lithium sector. If the new Chilean government manages to establish a clearly defined legal framework that applies equally to all companies, greater investment security and better use of the country's immense resources could result. Overall, Latin America will increase its share of total supply to around 33 % by 2030, becoming the second major pillar of total market supply alongside Australia.

In addition to Chile, other countries are also planning to restructure or update their raw materials policies for lithium or have already done so (e. g. Bolivia, Mexico, Serbia, the United States and Canada). Future supply will, to a large extent, depend on developments in these countries.

In Europe, there is no primary lithium extraction, although it has considerable resources. As of now, possible battery cell manufacturing capacities of up to 1,300 GWh have been announced for Europe. If battery cell production did develop in Europe and specifically in Germany, the European industry would significantly depend on imports of precursors. The results of this study show that Europe could cover about 27 – 34 % of its demand from own supplies in a scenario presented here (demand for 97,000 t of Li content in 2030). Around 3 – 10 % of European demand could be met from recycling.

Generally speaking, a massive expansion of global lithium extraction in the next few years will be necessary to meet the predicted policy-driven global demand. An increase by a factor of four to seven compared to 2020 would appear necessary. Processing capacities will also have to be expanded. While that in itself will present enormous challenges for the mining and processing sectors, this expansion will also have to be sustainable. Depending on the process route chosen, production will be associated with different levels of GHG emissions and energy and water consumption.

The industry concentration for lithium also remains oligopolistic. In 2020, the five largest companies supplied around 70 % of the global mining and processing output, and that is unlikely to change significantly by 2030. There may be additional industry consolidation or strategic joint ventures between individual businesses. Moreover, the processing industry (cell and car manufacturers) is likely to acquire stakes in primary extraction. Primarily these would be companies from Asia, but increasingly also European industry. Common hedging tools alongside direct holdings in the form of joint ventures are memoranda of understanding (MOUs), letters of intent (LOIs) and offtake agreements.

Most of the future project companies analysed in this study have already signed such agreements. Another phenomenon observed is the tendency of exploration projects to explicitly gear their planned output to the battery industry in terms of product qualities. This shift affects particularly traditional lithium applications such as the glass and ceramics sectors.

In order to assess the supply needed in future for a supply/demand balance, two supply scenarios for 2030 were developed. For projection of future demand, annual growth rates of 15.6 %, 19.1 % and 22.4 % were assumed. These are equivalent to demand of around 316,307–558,780 t of Li content (1,683,704–2,974,386 t of LCE). In supply scenario 1, around 271,889 t (approx. 1,159,823 t LCE) of lithium from mining production (incl. recycling) would be available on the market in 2030. In supply scenario 2, it would be about 357,680 t of lithium (approx. 1,903,930 t LCE).

If the lithium market were to develop as forecast in supply scenario 1, supply deficits of around 98,420 t, 208,830 t and 340,890 t of lithium would result for the different demand growth rates. With such high supply deficits, the implementation of individual projects would likely be accelerated or production upscaled by existing companies. All three deficits would result in considerable price and supply risks and the goals set for global market penetration of e-mobility could thus not be fully implemented.

If market developments were to follow the more likely supply scenario 2, an annual demand growth rate of 15.6 % would result in an excess supply of around 41,370 t. Annual demand growth rates of 19.1 % and 22.4 % would result in deficits of 69,040 t and 201,100 t respectively in this scenario.

In this context, it is important to remember that a potential excess supply from mining does not necessarily result in an excess supply of lithium chemicals.

Depending on the scenario, hard rock deposits would account for around 50–60 % of supply in 2030. These deposits would need to be converted to the relevant lithium chemicals, with adequate refinery capacities required to obtain the necessary quantity and quality of such chemicals. Many projects are also planning to use DLE processes in extraction, which would need to be established on an industrial scale to deliver the required quantities.

Until 2030, the processing of lithium carbonate, originating mainly from Chile and Argentina, will probably continue to be concentrated primarily in the Asian region, and most processing of spodumene concentrates from Australia to lithium hydroxide will continue to be in China. There are, however, first signs of a shift towards the processing and refining of precursors in Europe. Some companies have announced their intention to this effect or have already started implementation.

The supply of secondary lithium is currently of minor importance. Because of the dissipative distribution in the different end products and the required product qualities, recovery is not yet economically viable at present. The recycling of lithium-ion batteries, however, is possible and the relevant large-scale processes are available. This industrial sector is in fact under development, particularly in Europe. As the results of this study show, around 3 – 9 % of global demand in 2030 could be met from recycling. The introduction and drafting of relevant legal recommendations are also at the implementation stage.

Based on the results of this study, German businesses processing lithium themselves or using it in their products should in the short term adopt suitable alternative strategies such as long-term supply contracts or direct project participation, to hedge against potential supply bottlenecks and strong price increases.

1 Lithium as a raw material

1.1 Introduction

Lithium (Li, from Greek: **li**thos) is a light metal with the atomic number 3. In the periodic table of elements, it is found in the second period and the first main group. Its abundance in the Earth's crust is about 6 x 10^{-3} %.

Lithium in its elemental form is a soft, silvery-white alkali metal. Under standard conditions, it is the lightest of all solid elements. Lithium has the highest specific heat capacity and the highest melting and boiling points among the alkali metals. In its elemental state, it has the highest hydratation enthalpy of all alkali metals and therefore very strongly attracts water. Like all alkali metals, elemental lithium is highly reactive and reacts violently with many elements. Because of its reactivity, lithium is stored in paraffin oil or petroleum. Lithium reacts strongly with oxygen to form lithium oxide.

In scientific publications, company reports and presentations, lithium content is generally given in units of LCE (lithium carbonate equivalent) or as Li_2O content. One thousand tonnes of lithium metal are equivalent to 5,323 t of $LiCO_3$ (LCE) or 2,153 t of Li_2O (Table 1).

1.2 Deposits, extraction and processing

Deposits

The most important sources of lithium in economic terms are at present **hard rock deposits** (Table 2) and **brine deposits** (Table 3). In the current market situation, pegmatite deposits account for around 60 % of the global lithium supply.

Hard rock deposits: Because of its chemical properties, lithium stays in magmatic fluid phases for a long time. Primary hard rock deposits are therefore found predominantly in pegmatites and in the marginal areas of alkaline intrusions. Major deposits are located in Australia, Canada and Africa (e.g. DR Congo, Mali, Zimbabwe, Mozambique). Around 200 minerals contain lithium in concentrations > 0.002 % Li_2O, about 25 of them in concentrations > 2 % Li_2O (Garret 2004). However, not many of them are economically viable. The most important minerals for lithium extraction are listed in Table 2. Other valuable minerals are frequently found in these pegmatites as well, containing, for instance, tantalum, niobium, tin, tungsten, caesium, rubidium, boron, fluorine and other rare elements.

Lithium-bearing clays are formed by the weathering of lithium-bearing intrusive volcanic rock. Additional enrichment can result from hydrothermal processes. The most important of these clay minerals belong to the smectite group, particularly

Table 1: Conversion factors for lithium and lithium compounds.

Starting compound	Formula	Li content (%)	convert to Li	convert to LiO_2	convert to Li_2CO_3
Lithium	Li	100	1	2.153	5.323
Lithium oxide	LiO_2	46.5	0.464	1	2.743
Lithium fluoride	LiF	26.8	0.268	0.576	1.420
Lithium carbonate	Li_2CO_3	18.8	0.188	0.404	1
Lithium hydroxide monohydrate	$LiOH \cdot H_2O$	16.5	0.165	0.356	0.880
Lithium chloride	LiCl	16.3	0.163	0.362	0.871
Lithium hypochloride	LiOCl	11.89	0.119	0.256	0.633
Lithium bromide	LiBr	8	0.080	0.172	0.425
Butyllithium	C_4H_9Li	10.83	0.108	0.233	0.576

the end member hectorite (Table 2). Major deposits can be found in the United States (Nevada, California, Utah, Oregon, Wyoming, Arizona and New Mexico; Roskill 2016).

Lithium also occurs in lithium iron micas (e.g. zinnwaldite). Zinnwaldite is the group name for the series between siderophyllite and polylithionite (end members). Lithium iron micas are therefore part of the phlogopite group. The type locality for zinnwaldite is Zinnwald (Zinnwald-Georgenstadt) in the Ore Mountains. Zinnwaldite has a relatively low lithium content and relatively high iron and fluoride contents, and it is therefore harder to process and extract lithium from than other ores (pegmatites).

Another source of lithium is the mineral jadarite (Table 2), a sodium lithium boron silicate hydroxide with a lithium content of up to 7.3 %. Its type locality is the Jadar Valley in Serbia (Section 2.6.3).

Brine deposits: Lithium-bearing groundwater occurs mainly in three different environments: in salt lakes (salars) or playas (salt pans), continental brines and oilfield brines. At present, only the deposits in salt lakes are being exploited, although increasing assessment of the resources in continental brines is now taking place.

In hydrogeological terms, these deposits are highly complex systems, with vast differences between individual salars. They are generally characterised by a high altitude and low precipitation.

The lithium in these deposits probably originates from deep geothermal groundwater or hot springs (Garret 2004). Small quantities of lithium may also originate from the leaching of lithium-bearing minerals (volcanic ashes, clays). The lithium content varies widely between salars (Table 3). For the Salar de Atacama, for instance, it is 1,500 ppm on average (see Schmidt 2017).

In recent years, attention has increasingly focused on the potential of lithium extraction from **continental brines** (Table 4). Particularly in the United States (e.g. Salton Sea) and in Europe (e.g. Upper Rhine Graben), research is carried out into this potential and projects in this field are under development. In Europe, the potential is linked to deep geothermal energy, and there are plans for the extraction and production of lithium in combination with heat and power generation.

The Li^+Fluids project, for instance, has as its overriding goal the completion of a comprehensive potential study for the whole of Germany on the extraction of lithium from hydrothermal fluids (Bundesverband Geothermie 2022). The study will

Table 2: Major lithium-bearing minerals (data source: BGS 2016, Roskill 2016, Garret 2004).

Minerals	Formula	Li content (%)	Avg. Li cont. in ores (%)
Spodumene	$LiAlSi_2O_6$	1.9 – 3.7	1.35 – 3.6
Petalite	$LiAlSi_4O_{10}$	1.6 – 2.27	1.4 – 2.2
Lepidolite	$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$	1.39 – 3.6	1.4 – 1.9
Amblygonite	$(Li,Na)AlPO_4(F,OH)$	3.4 – 4,7	n/a
Eucryptite	$LiAlSiO_4$	2.1 – 5.53	2.1 – 4.4
Bikitaite	$LiAlSi_2O_6 \cdot H_2O$	3.4	n/a
Hectorite	$Na_{0,3}(Mg,Li)_3Si_4O_{10}(OH)_2$	0.24 – 0.54	n/a
Salitolite	$(Li,Na)Al_3(AlSi_3O_{10})(OH_5)$	0.77	n/a
Swinefordite	$Li(Al,Li,Mg)_4((Si,Al)_4O_{10})_2(OH;F)_4 \cdot nH_2O$	1.74	n/a
Zinnwaldite[1)]	$K(Li,Fe^{2+},Al)_3[(F,OH)_2\|AlSi_3O_{10}]$	0.92 – 1.85	n/a
Polylithionite	$KLi_2AlSi_4O_{10}(F,OH)_2$	n/a	n/a
Jadarite	$LiNaSiB_3O_7(OH)$	7.3	n/a

[1)] Group of the two end members siderophyllite ($K(Fe^{2+},Al)_3[(F,OH)_2|(Si,Al)_4O_{10}]$) and polylithionite ($KLi_2Al[F_2|Si_4O_{10}]$)

Table 3: Average concentration of lithium, magnesium, potassium, sodium, sulphate and chloride in individual lithium deposits (data source: Garret 2004, Roskill 2016, BGS 2016, Neolithium 2017, Li3 Energy 2016).

Deposits	Loc.	Avg. Li (ppm)	Avg. Mg (ppm)	Avg. K (ppm)	Avg. Na (ppm)	Avg. SO_4 (ppm)	Avg. Cl (ppm)	Mg/Li	K/Li	SO_4/Li
Salars										
Salar de Atacama	Chile	1,570	9,650	23,600	91,000	15,900	189,500	6.15	15.03	10.12
Salar de Maricunga		1,250	8,280	8,869	n/a	7,200	n/a	6.63	8.6	5.76
Salar de Hombre Muerto	Argentina	190 – 900	180 – 1,410	2,400 – 9,700	99,000 – 103,000	5,300 – 11,400	158,000 – 168,000	0.94 – 1.56	10.77 – 12.63	12.66 – 27.89
Salar de Olaroz[1]		610 – 695	1,450[2]	5,730	n/a	16,287[3]	n/a	2.37[1]	9.39 – 8.24	26.7[1]
Salar de Rincon		397	3,415[2]	7,513	n/a	12,228[3]	n/a	8.6	18.9	30.8
Salar des tres Quebradas[4]		858	1,363	7,682	78,782	554	191,289	1.59	8.9	0.65
Salar de Los Angeles		501	1,904[2]	6,206	n/a	7,315[3]	n/a	3.8	n/a	14.6
Sal de Vida		782	1,720[2]	8,653	n/a	8,993[3]	n/a	2.2	11.1	11.5
Salar de Cauchari		618	1,792[2]	5,127	n/a	19,096[3]	n/a	2.9	8.3	30.9
Salar de Centenario		560	3,260	5,111	n/a	n/a	n/a	5.87	9.20	n/a
Mariana		300 – 341	n/a	8,740 – 10,655	n/a	n/a	n/a	n/a	n/a	n/a
Salar de Uyuni	Bolivia	349	6,500	7,200	87,200	8,500	157,100	18.62	20.63	24.35
Clayton Valley	USA	163	190	4,000	46,900	3,400	72,600	1.17	24.54	20.86
Silver Peak		245	343[2]	5,655	n/a	7,571[3]	n/a	1.4	23.1	30.9
Searless Lake		54 – 60	n/a	1,570 – 2,530	110,800 – 118,400	4,440 – 4,610	108,100 – 123,000	n/a	26.2 – 46.9	74 – 85.4
Great Salt Lake		18	5,000 – 9,700	2,600 – 7,200	37,000 – 87,000	9,400 – 20,000	70,000 – 156,000	277.8 – 538.9	144.4 – 400	522.2 – 1,111.1
Bonneville		57	4,000	5,000	83,000	n/a	140,000	70.2	87.7	n/a
Zabuye Caka	China	489	26	16,600	72,900	27,100	123,000	0.05	33.9	55.4
Da Qaidam (Quaidam Basin[5])		182	11,700	3,600	77.700	20,400	141,600	64.3	19.8	112
Taijinaier		310	20,200	4,400	56,300	34,100	134,200	65.2	14.2	110
Dead Sea	Israel	12	3,090	5,600	30,010	610	161,000	257.5	466.7	50.8
Sua Pan	India	20	n/a	2,000	60,000	8,300	70,900	n/a	100	415

Deposits	Loc.	Avg. Li (ppm)	Avg. Mg (ppm)	Avg. K (ppm)	Avg. Na (ppm)	Avg. SO_4 (ppm)	Avg. Cl (ppm)	Mg/Li	K/Li	SO_4/Li
Oilfield Brines										
Smackover (1976)	USA	146	2,900	2,400	56,900	375	144,500	19.9	16.4	2.6
Smackover (1984)		170	3,500	2,800	67,000	450	171,700	20.6	16.5	2.6

[1] Based on data provided by the company Orocobre (2016);
[2] calculated from the Mg/Li ratio;
[3] calculated from the SO_4/Li ratio;
[4] based on data provided by the company Neolithium
[5] basin comprises these lakes: Qaidam, Kiao Quaidam, Mahai, Quinghai.

Table 4: Average concentration of lithium, magnesium, potassium, sodium, sulphate and chloride in deep geothermal continental brines (data source: Garret 2004, Sanjun et al. 2022).

Deposits	Loc.	Avg. Li (ppm)	Avg. Mg (ppm)	Avg. K (ppm)	Avg. Na (ppm)	Avg. SO_4 (ppm)	Avg. Cl (ppm)	Mg/Li	K/Li	SO_4/Li
Geothermal brines										
Cerro Prieto	Mexico	393	n/a	36,000	70,000	n/a	159,000	n/a	91.6	n/a
El Tatio Hot Springs	Chile	38	2.2	357	3,620	36	6,470	0.06	9.4	0.95
Salton Sea	USA	100 – 400	700 – 5,700	13,000 – 24,000	50,000 – 70,000	42,000 – 50,000	142,000 – 209,000	7 – 14.3	130 – 240	420 – 500
Paradox Becken		110	30,900	26,700	25,200	22	201,000	281	243	0.2
Campi Flegrei	Italy	480	n/a	43,400	85,200	n/a	314,000	n/a	90.42	n/a
Cesano C-1-1-3		250	12	88,000	61,000	191,000	28,000	0.05	352	0.76
Groß Schöne-beck GRSK-4	Ger-many	215	243	3,520	32,200	38	128,000	1.13	16.37	0.18
Molasse-becken HC-14		143	351	1,140	18,700	1,852	30,800	2.45	7.97	0.01
Illkirch	France	173	191	n/a	27,200	400	54,500	1.10	n/a	2.31
Vendenheim		162	66	3,880	28,600	n/a	62,000	0.41	23.95	n/a
Rittershofen GRT-1		190	138	3,790	28,500	220	59,900	0.73	19.95	1.16
Soultz-Sous-Forêt		173	131	3,190	28,100	157	58,600	0.76	18.44	0.91
Cronenbourg		210	126	4,030	31,500	480	62,000	0.60	19.19	2.29
Insheim	Ger-many	168	99	3,820	29,900	131	64,900	0.59	22.74	0.78
Landau		182	80	4,000	28,200	130	64,500	0.44	21.98	0.71
Bruchsal		159	301	3,110	35,100	267	73,600	1.89	19.56	1.68

contribute to the development of a (secondary) raw material strategy and provide a decision-making aid for the planning of geothermal sites with heat generation and additional raw material extraction. Among the partners in this joint research project are, for instance, the Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems (IEG) and the Federal Institute for Geosciences and Natural Resources (BGR). The project receives funding from the Federal Ministry for Economic Affairs and Climate Action (BMWK).

The aim of the UnLimited joint project is the development and testing of a process that will permit lithium production from extracted deep groundwater alongside its geothermal energy use. Project partners are the Karlsruhe Institute of Technology (KIT), Hydrosion GmbH, the University of Göttingen, EnBW AG and BESTEC GmbH. This project also receives funding from the BMWK (Unlimited 2022).

Scientists from KIT have calculated the potential of geothermal systems as a lithium source in Germany and France based on the current state of development. According to Goldberg et al. (2022), they have a potential of around 1,353 t of lithium content (approx. 7,200 t LCE) annually. Other research topics are, for instance, the size and origin of lithium deposits, or the reactions and interactions that occur in the reservoirs during extraction.

Extraction/processing

Fig. 1 shows a highly simplified schematic diagram of the steps involved in conventional production and the most important intermediate products. Both lithium-bearing brines and mineral concentrates can supply products that are equivalent in quality but they have different process routes and ecological footprints (GHG emissions; Section 1.3).

A detailed illustration of the conventional process routes for the extraction of lithium from hard rock and brine deposits can be found in Schmidt (2017).

The share of global lithium extraction from pegmatite deposits has greatly increased in recent years (Section 2.2.1). This is primarily due to projects in Australia implemented with outside funding. The spodumene concentrates produced there continue to be mainly exported to Asia (China) for processing into battery precursors (lithium carbonate and hydroxide). However, there are first signs of a shift towards local value chains. The company Lithium HoldCo (Tianqi Lithium/IGO), for instance, commissioned a processing plant at Kwinana that produced its first battery-grade lithium hydroxide in May 2022 (S&P Global 05/2022). Planned as a joint venture, the Kemerton processing plant (Albemarle/Mineral Resources) is currently under construction and due to be commissioned in late 2022 (Mineral Resources 2022). Other Australian businesses, such as Pilbara Minerals (Pilgangoora), Westfarmers (Mt. Holland) or Liontown (Kathleen Valley), are also considering entry into a

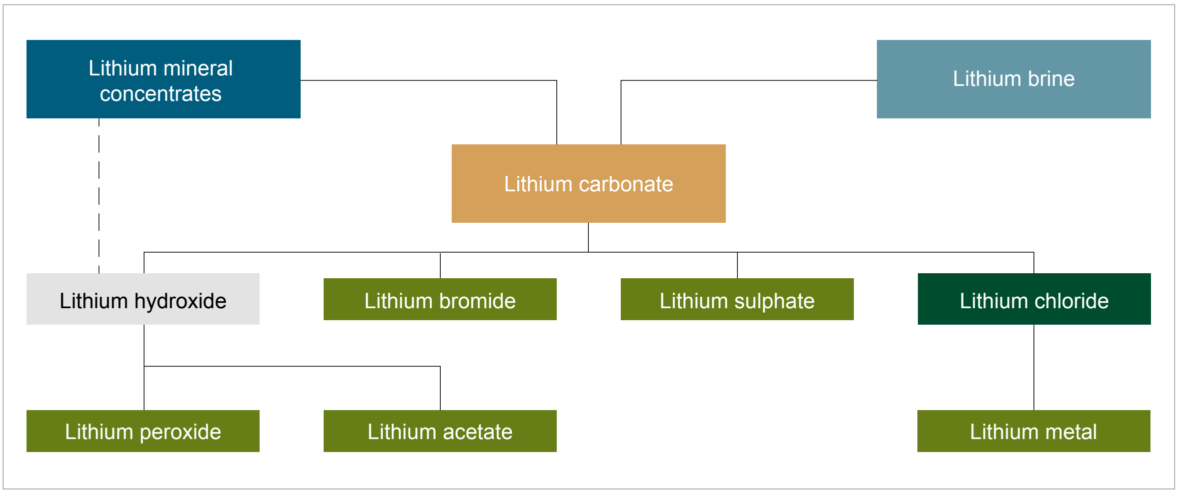

Fig. 1: Simplified schematic diagram for the production of lithium and major lithium compounds (adapted from Roskill 2016).

higher level of the value chain. Comparable plans can be found in other producer countries or projects located in those countries.

In Europe, there are similar developments. Processing facilities for imported concentrates and base products are to be built, and exploration projects are planning to produce higher-value products (lithium carbonate and hydroxide) alongside the extraction of raw materials. At present, around 20 known projects across Europe are aiming to produce higher-value lithium products, such as in Finland, Portugal, France, the United Kingdom, Austria, Serbia and Germany. Rocktech Lithium are planning to build up to five converters in Europe, the first of them in Guben, Brandenburg (Rocktech Lithium 2021), while AMG Lithium GmbH have already started on the construction of a refinery to produce lithium hydroxide at the Bitterfeld/Wolfen chemical park (AMG Lithium 2022). Vulcan Energy, too, are planning to build a plant for the extraction of lithium and production of lithium hydroxide (Vulcan Energy 05/2022).

Lithium from brines is still extracted mainly in the so-called "Lithium Triangle" in South America (Chile, Argentina, Bolivia) using the methods described by Schmidt (2017). Particularly in Chile, the industry focus is on more sustainable and socially and environmentally compatible extraction/production (Section 1.3). As with hard rock deposits, efforts are being made to establish local downstream value chains. Process optimisation, new technological approaches for greater efficiency in production, and alternative production methods such as DLE (direct lithium extraction) will continue to gain in importance.

1.3 Ecological and socioeconomic aspects

Extraction from hard rock deposits and extraction from brines have very different environmental impacts, and their individual sustainability aspects must therefore be considered separately. Depending on the source, the end products lithium carbonate and lithium hydroxide, and thus also the products they are used in, have different environmental footprints.

In the next few years, it will be necessary to greatly expand lithium extraction. While that in itself presents enormous challenges for the mining and processing sectors, this expansion will also have to be sustainable.

Extraction from hard rock

Lithium from hard rock is mostly extracted in open-cast mining. This involves first of all removal of the overburden and gangue material, which are moved to dumps, possibly resulting in dust pollution. The stripping ratio for lithium pegmatites generally ranges from 3:1 to 10:1, i.e. 3–10 t of waste material are produced per ton of ore. The land use of an open-cast mine depends on its location and can therefore vary considerably. In arid regions with low population density, such as northern Australia, it is less of a problem than in densely populated areas (see Drobe 2020). Conflicts over use are therefore specific to an individual deposit.

The production of lithium concentrates from hard rock requires water. Before they are transported, these concentrates are additionally dewatered and the residues are discharged into tailings ponds. Some of the water recovered there can be reused, while some remains in the tailings in the form of pore and adhesive water (around 40 % of the volume). Thickeners or filter presses can be used for dewatering tailings to reduce water losses. A residual moisture of between 15 and 25 % can be achieved with filter presses. Nevertheless, around 500,000 m^3 of water are still needed for an ore throughput of 5 m t per year. Unlike with metal mining (for copper, lead, zinc and gold concentrates), there is normally no sulphide mineralisation with lithium, so an acidification of the groundwater or surface water is unlikely.

At present, most of the concentrates thus produced are shipped to China for processing. Transportation already produces considerable amounts of greenhouse gases. Concentrates contain no more than 6 % Li_2O (2.8 % Li content) and processing therefore produces large volumes of gangue material. In 2020, Australia exported around 1.6 m t of concentrates to China. Based on an average Li_2O content of 6 %, that is equivalent to around 41,800 t of Li content and more than 1.5 m t of waste material. Then there is process waste. According to industry insiders, a total of up to 10 t of waste (e.g. slag) is produced per ton of end product. Although this cannot be fully reused at present, some projects in science and industry are already studying the potential for use of this waste from production. Set up in 2021, ITEL – Deutsches Lithiuminstitut GmbH is one company working in this area. It focuses on CO_2-neutral production, developing an integrated lithium economy including the use of by-products, establishing a European circular economy for lithium based on digital twins, and international standards for the relevant ESG criteria (Itel 2022). At the company level, efforts are also being made to set up the processing of these concentrates in Europe using modified processes and to make use of the waste products.

The processing, including chemical processing, of the concentrates to lithium carbonate or lithium hydroxide requires large amounts of energy and water, resulting in a high level of CO_2 emissions (Table 5).

Extraction from brines

Lithium extraction from brines requires much more differentiated consideration, due to controversies surrounding this industry, particularly in Chile, where there are competing economic, social and political interests (Section 2.6.2). Due to the country's large market share, the particular situation in Chile is considered below.

Generally speaking, the solar evaporation ponds account for most of the land use in the salars. SQM (Salar de Atacama) has evaporation ponds that extend across an area of around 19 km² (lithium extraction), while the size of Albemarle's ponds (ALB) is about 6 km². For context, the whole Salar de Atacama has an area of around 3,000 km². Additional space is needed in the salars to deposit salts for which there is currently no significant commercial use. The surface area required for this is relatively small compared to the evaporation ponds, especially since the industry is keen to sell these products in future. The mineral bischofite, for instance, is used in road construction. When mixed with water, it can help reduce dust formation on roads. Sylvinite and carnalite are salts that can be sold to the fertiliser industry. There is no other land use in the salars.

The most important issues at the Salar de Atacama and other salars in South America include water use and the impact of brine extraction on the ecosystems of these arid regions. Water use is often misunderstood, as evaporation ponds in the desert suggest a high consumption of water that could be used for other purposes. The terms brine, fresh water and process water are therefore frequently used synonymously.

Brines extracted from the salars have an average salt content (TDS) of around 350 kg/m³. Sea water, by comparison, typically has a content of about 35 kg/m³ and the Dead Sea of around 240 kg/m³. The extracted brine could not be used for any other purpose. In Chile, it is defined as a mineral resource and not as groundwater. This is another point of contention or criticism, because, in chemical terms, brine has a water content of about 70 %. Because of this definition, the share of water that evaporates is not considered in some LC analyses and comparability is often not possible.

Generally speaking, the brine pumped to the surface is evaporated in the evaporation ponds. This precipitates undesirable salts and increases the lithium concentration (6 % Li content). According to Kelly et al. (2021), around 24 t of brine are needed to produce one ton of concentrated brine (6 % Li content), and 4 t of concentrated brine for each ton of lithium carbonate.

For the Salar de Atacama (Chile), maximum permitted brine extraction volumes are set by CORFO or contracts with SQM (1,600 l/s) and ALB (443 l/s). Extraction indisputably removes brine from the salar system and the extraction process is closely monitored and recorded. Both CORFO and companies working at the site have their own hydrogeological models for monitoring the impact on the system as a whole (input-output model). At https://www.sqmsenlinea.com/, for instance, SQM has made available a freely accessible real-time online monitoring system (SQM 06/2022) with real-time data from the Salar de Atacama. The longterm impact of brine extraction is also the subject of scientific studies and joint research projects (e.g. BrineMine). Moreover, both SQM and ALB are working on extracting less brine while at the same time increasing output. They are hoping to achieve this through process optimisation and additional process steps. New extraction technologies such as DLE (direct lithium extraction) may also be used. Many new planned exploration projects aim to rely exclusively on these selective extraction methods. Other well-established producers are also working on optimising their processes, in Argentina, for instance.

Fresh water is needed in a salar for steps such as the removal of salt accretions from the equipment or, in the case of SQM, the treatment of the potassium salts produced and for their process route. Not all water extracted is thus used in lithium production. The fresh water is drawn from wells outside the salar, with legal rules specifying the precise volumes permitted. The above use of this resource essentially competes with use by the local population, tourism, and other sectors such as the copper industry.

Albemarle holds around 0.5 % of all fresh-water rights in the Salar de Atacama, but, according to its own figures, is now using only 9 l/s of the 24 l/s available (Albemarle 2020). Because of its size and business orientation, SQM holds around 6.9 % of the water rights in the Salar de Atacama, but, according to its own figures, used only 2.1 % in 2020 (SQM 03/2021). The other sectors of industry (mainly copper) together hold more than 50 % (> 2,300 l/s) of the water rights. The remaining 41 % (> 2,200 l/s) are held by agriculture, tourism, and the general population, with tourism accounting for the largest share.

The brine concentrated in the salar is transported by tank truck to the processing plants at La Negra (ALB) and La Carmen (SQM) outside Antofagasta, where it is processed. Most of the water required in the processing facilities is industrial and residential effluent that has been treated. It is circulated and recovered. Some of the water is used to dilute the brine to a concentration of less than 1.2 %. Water is also needed to produce lithium hydroxide from lithium carbonate. Table 5 shows the energy and water consumption for the production of lithium carbonate and lithium hydroxide based on Kelly et al. (2021).

Thermal evaporators, a technology used by SQM and ALB, can further reduce water consumption. In early 2022, Albemarle put such a plant into continuous operation at La Negra. According to the company, it reduces fresh water consumption by 30 % (Albemarle 2021). Moreover, both companies are evaluating the use of water from seawater desalination.

In early 2022, the Chilean State Defense Council (Consejo de Defensa del Estado, CDE) sued the companies BHP Minera Escondida (copper), Compania Minera Zaldivar S. A. (copper) and Albemarle (lithium) regarding water extraction from the Monturaqui-Negrillar-Tilopozo aquifer (Primer Tribunal Ambiental Republica de Chile 2022) outside the Salar de Atacama. The groundwater level in this location has dropped considerably, allegedly due to the extraction of water by Escondida (Monturaqui), Zaldivar (Negrillar) and Albemarle (Tilopozo). Until 2019, BHP Escondida extracted around 1,400 l/s. Zaldivar has a current licence for extraction of up to 500 l/s until 2025 and currently extracts around 213 l/s. Albemarle, by contrast, used to extract just 17 l/s, i.e. around 1.2 % of the volume used by BHP. Nevertheless, all three companies face the same charges. In addition, the lithium production licences awarded to BYD Chile SpA and Servicios y Operaciones Mineras del Norte S.A. (Gruppo Erazuris) were revoked in early June 2022, after indigenous communities had brought legal action because they had not been consulted (Section 2.6.2).

The dialogue with and consultation of the indigenous population regarding this industry play an important role in Chile. The same is true in Argentina and Bolivia, where water consumption and environmental impacts resulting from extraction are other major issues.

Lithium compounds produced in South America are also transported by ship and therefore associated with high greenhouse gas emissions.

Data from Kelly et al. (2021) reveal that both energy and water consumption are higher for the hard rock process route than for the brine process route. The CO_2-equivalent footprint of lithium carbonate produced from brine is lower by a factor of around 7 than lithium carbonate produced from hard rock via the Australia/China process route. In the case of lithium hydroxide, the footprint of production from brine is smaller by a factor of 2. This difference is smaller because of the process route: production from brine is via lithium carbonate, while this intermediate step is not necessary for hard rock deposits. The use of regenerative energy sources could improve GHG emissions of this process route in China and other countries. According to Kelly et al. (2021), water consumption per ton of output is also significantly higher for production from hard rock than from brine.

Table 5: LCA results for lithium carbonate and lithium hydroxide from hard rock and brine deposits (data source: Kelly et al. 2021).

Deposits	Process step	GHG emissions [t CO_2e/t]	Energy [MJ/t]	Fresh water [m³/t]
Brine	Concentration	0.08 – 0.18	1,300 – 2,800	2.95 – 7.3
	Li_2CO_3 production	2.7 – 3.1	30,000 – 36,000	15.5 – 32.8
	LiOH production	6.9 – 7.3	76,600 – 82,900	31 – 50
Hard rock	Concentration	~ 0.42	~ 5,500	~ 3.4
	Li_2CO_3 production	~ 20.4	~ 218,000	~ 77
	LiOH production	~ 15.7	~ 187,200	~ 69

Extraction from continental brines

Companies and research organisations in several countries are evaluating the extraction of lithium from continental brines and testing it in pilot plants. In the United States, the companies Berkshire Hathaway Energy, Energy Sources and Controlled Thermal Resources (CTR) are actively working in Imperial Valley (Salton Sea) on geothermal energy and possible lithium extraction. In Germany, the utility company ENBW is assessing this type of extraction at the Bruchsal site in the Upper Rhine Graben as part of its UnLimited innovation project. In their project Zero Carbon Lithium, Vulcan Energy are planning to integrate lithium production with deep geothermal power in Germany.

In the best case, the deep groundwater will be used first for power generation and then for direct lithium extraction (DLE). Conventional evaporation ponds will therefore not be needed, significantly lowering land use by comparison. The concept of extraction integrated with geothermal power generation could result in a considerably lower CO_2-equivalent footprint per ton of output. Vulcan Energy have indicated a CO_2-equivalent footprint per ton of lithium hydroxide of zero. Fresh water consumption is given as 80 m³/t of lithium hydroxide (Vulcan Energy 04/2022). With the proximity of potential end markets in Europe, shorter transportation routes should theoretically be possible. At present, however, the production potential is still limited according to Goldberg et al. (2022).

Toxicological classification

Depending on the lithium product, the hazard potential of the material and accordingly its classification vary. According to the European Chemicals Agency (Echa), lithium metal (CAS 7439-93-2) causes severe skin burns and eye damage on contact (Echa 2022a). In contact with water, it releases flammable gases, which is why it is transported in paraffin oil. In contact with oxygen, it is oxidised to lithium oxide in an exothermic reaction (see Schmidt 2017).

Lithium chloride (CAS 7447-41-8) is classified by ECHA 2022b as harmful if swallowed and causing serious eye irritation and skin irritation. Lithium carbonate (CAS 554-13-2) is harmful if swallowed and also causes serious eye irritation (ECHA 2022c). Lithium hydroxide (CAS 1310-65-2) is toxic if swallowed and causes severe skin burns and eye damage (ECHA 2022d).

In June 2020, the French Agency for Food, Environmental and Occupational Health & Safety (Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, ANSES) submitted an application to have lithium chloride, carbonate and hydroxide classified as Repr.1A (H360FD) under the REACH Regulation (ANSES 2020). The deadline for comments expired in December 2021. Although the final decision is still outstanding, it is unlikely that this classification will be rejected. A decision is expected in late 2022 or early 2023.

Because of stricter safety regulations, the classification could lead to higher costs, which could affect the production, transportation, handling and recycling of products containing these compounds. It is not clear at present what impact the classification would have on the competitiveness of the European battery industry. According to Reuters (07/2022), Albemarle, for instance, could be forced to abandon its production site at Langelsheim.

1.4 Use

Because of its very specific properties, lithium is used in many products. The most important application of lithium by far is **rechargeable batteries**, the second most important **ceramics/glass-ceramics/glass**. A detailed description of the individual areas of application for lithium can be found in Schmidt (2017).

While **rechargeable batteries** accounted for only 37 % of lithium use in 2015 according to Roskill (2016), this had risen to 67.1 % by 2020 (CRU 2022; Fig. 2), most of this share for use in e-mobility. **Ceramics/glass-ceramics/glass** accounted for a cumulative share of around 26.5 % in 2015 (Roskill 2016). This had declined to just 16.1 % by 2020 (CRU 2022; Fig. 2). Depending on which data source is used, both areas of application together accounted for around 83–85 % in 2020, "Other applications" for the remaining 15–17 %.

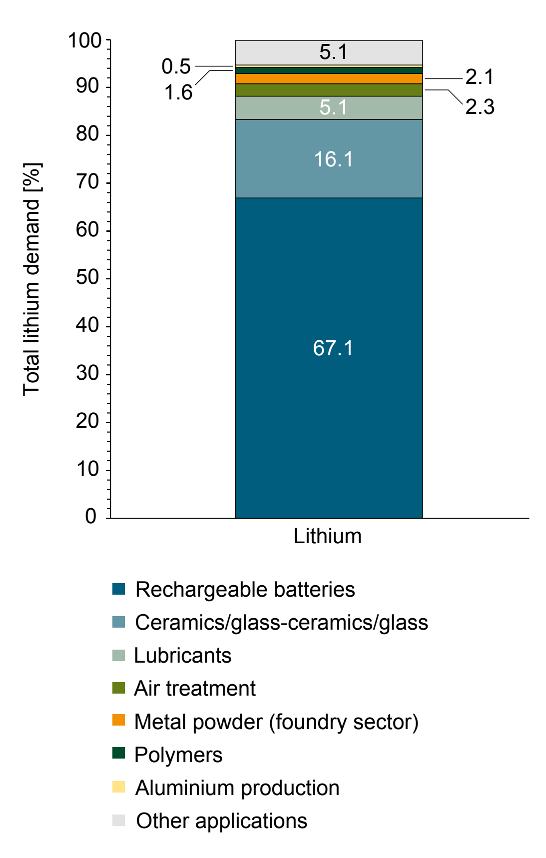

Fig. 2: Areas of application for lithium in 2020 (data source: CRU 2022).

2 Raw material risk assessment

2.1 Price trends and risks

Lithium is traded primarily in the form of mineral concentrates (spodumene, petalite) and the two most important intermediate products, lithium carbonate and lithium hydroxide, in a range of different qualities. There is also some trade in small quantities of lithium-rich brines, and lithium chlorides, bromides and metal.

Prices are agreed on an individual basis by producers and consumers, and depending on the required product qualities and specifications (long-term supply contracts). There is also some trade in lithium products on spot markets. Prices are generally determined by supply and demand. Some spot market prices for lithium carbonate and spodumene concentrates are considerably higher than long-term supply contract prices.

Since mid-2021, lithium has been traded on the London Metal Exchange (LME) as "LME battery-grade hydroxide cash-settled future". The parameters for this contract can be accessed at https://www.lme.com/en/Metals/EV/About-Lithium/Contract-specification. A Fastmarkets MB price is used as a basis: "lithium hydroxide monohydrate: min 56.5 % LiOH battery grade, spot prices CIF China, Japan and South Korea, $/kg" (LME 2022).

In May 2021, CME Group set up a lithium future (Lithium Hydroxide CIF CJK [Fastmarkets]) with the ticker symbol LTH. A similar cobalt future is already trading successfully. The parameters of this future can be found at https://www.cmegroup.com/trading/metals/other/lithium-futures.html (CME GROUP 2022).

2.1.1 Price data

Table 6 lists the specifications and time series for lithium raw materials and chemicals. Because of variations in their availability over time and in product and delivery parameters, they are not directly comparable. A detailed analysis of price trends up to and including 2016 can be found in SCHMIDT (2017).

Lithium carbonate

In late 2016, another price peak for lithium carbonate was emerging, due to forecasts of high demand from China and limited supply. Prices rose to all-time highs of around US$18,000–26,000/t depending on quality in late 2017 (Table 6, Fig. 3). This was followed by a period of plummeting prices, due to only a slight rise in demand, and, at the same time, a sharp increase in supply. Another factor was the start of the Covid-19 pandemic, which resulted in a collapse in prices from their record highs in 2017 by more than 76 % to around US$6,000–7,000/t in late 2020.

Table 6: Price data for lithium and lithium compounds (data source: BGR 2022).

Specification	Period
LITHIUM: Lithium carbonates, min. 99–99.5 % Li_2CO_3, large contracts, USA, delivered continental	06/1998–10/2020
LITHIUM: Lithium carbonates, min. 99.5 % Li_2CO_3, battery grade, spot price, ex works, domestic China	11/2017–04/2022
LITHIUM: Lithium carbonate, min. 99 % Li_2CO_3, technical and industrial grades, contract price ddp Europe and USA, $/kg	03/2019–04/2022
LITHIUM: Lithium hydroxide, Chinese, 56.5–57.5 % LiOH, packed in drums or bags, large contracts, del Europe	08/2015–04/2020
LITHIUM: Lithium hydroxide monohydrate min. 56.5 % $LiOH.H_2O$, battery grade, spot price ex works China	11/2017–04/2022
LITHIUM: Lithium hydroxide monohydrate min 56.5 % $LiOH.H_2O$, technical & industrial grade, contract price cif China, Japan & South Korea	11/2017–04/2022
LITHIUM: Spodumene, min. 5–6 % LiO_2, cif China	04/2015–04/2022

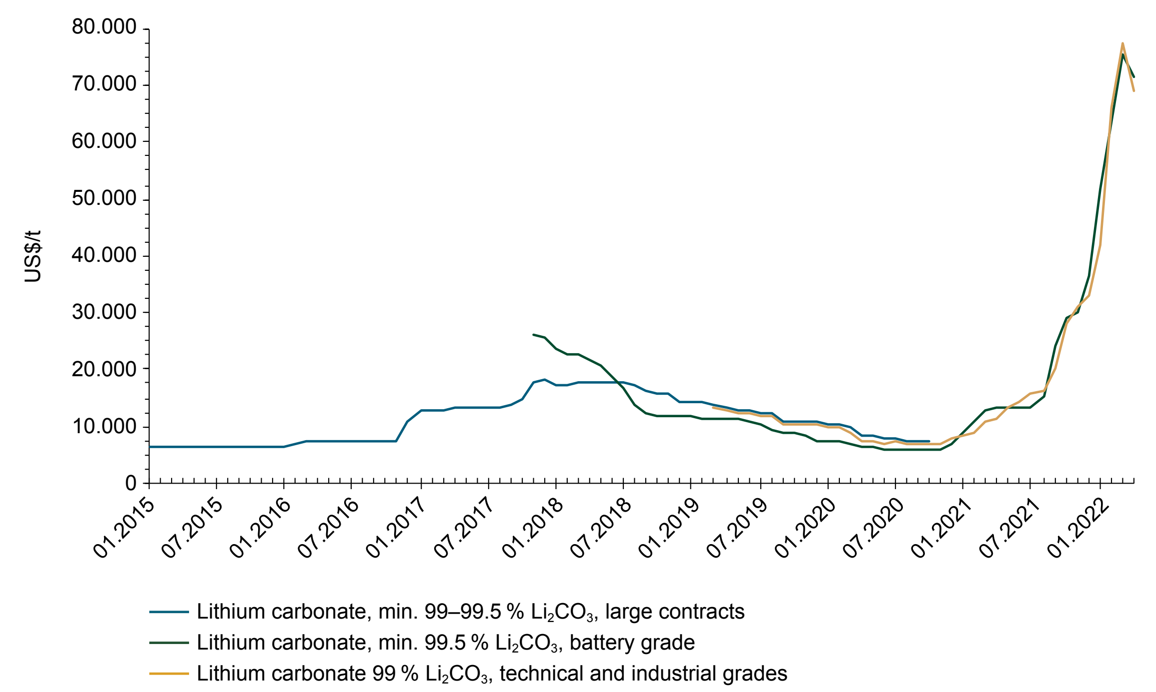

Fig. 3: Nominal prices for lithium carbonate (01/2015–04/2022; data source: BGR 2022).

Since this low-price period, the price for lithium carbonate has risen dramatically, reaching a historic all-time high of US$75,400–77,500/t in March 2022. Compared to December 2020, the price rose by almost 1,000 %, with the largest increase starting around October 2021. This is attributed to an enormous boom in demand from the e-mobility sector. At the same time, it is foreseeable that primary production and particularly the downstream industry are unlikely to be able to meet this demand. Since March 2022, a slight price correction of about 10 % has been recorded. With the car industry producing and selling far fewer cars because of supply issues, and demand cooling due to inflation, prices may decline further over the course of 2022. Corona restrictions in China have led to a marked slump in the sale and manufacture of vehicles. It is impossible to say at present when and how this situation will ease.

Lithium hydroxide

As with lithium carbonate, there were signs of a first high-price period for lithium hydroxide in late 2017 and mid-2018. Depending on quality (Table 6, Fig. 4), the price range was US$19,000–23,000/t. Again, as for carbonate, this was followed by a severe price decline of around 65 %, which bottomed out in December 2020 at about US$6,500–8,100/t.

Since this low-price period, the price for lithium hydroxide has also recovered and greatly increased. In March 2022, it reached historic all-time highs of US$64,000–73,300/t. Compared to December 2020, the price has thus risen by 1,000 %, as for lithium carbonate, with the largest increase from around December 2021 (133 %). At present, there are no signs of a price correction for lithium hydroxide.

Spodumene concentrates

The price for spodumene concentrates, a precursor of lithium carbonate and/or hydroxide, depends to a large extent on the Li_2O content. Like lithium carbonate and lithium hydroxide, spodumene concentrates saw a first high-price period in late 2017 to mid-2018, with prices just under US$1,100/t. Because of overproduction in 2018 and 2019, this was followed by a period of price decline lasting until around late 2020. At about US$375/t, the concentrate price was roughly 60 % lower than at its highest level in June 2018. Since then, prices have

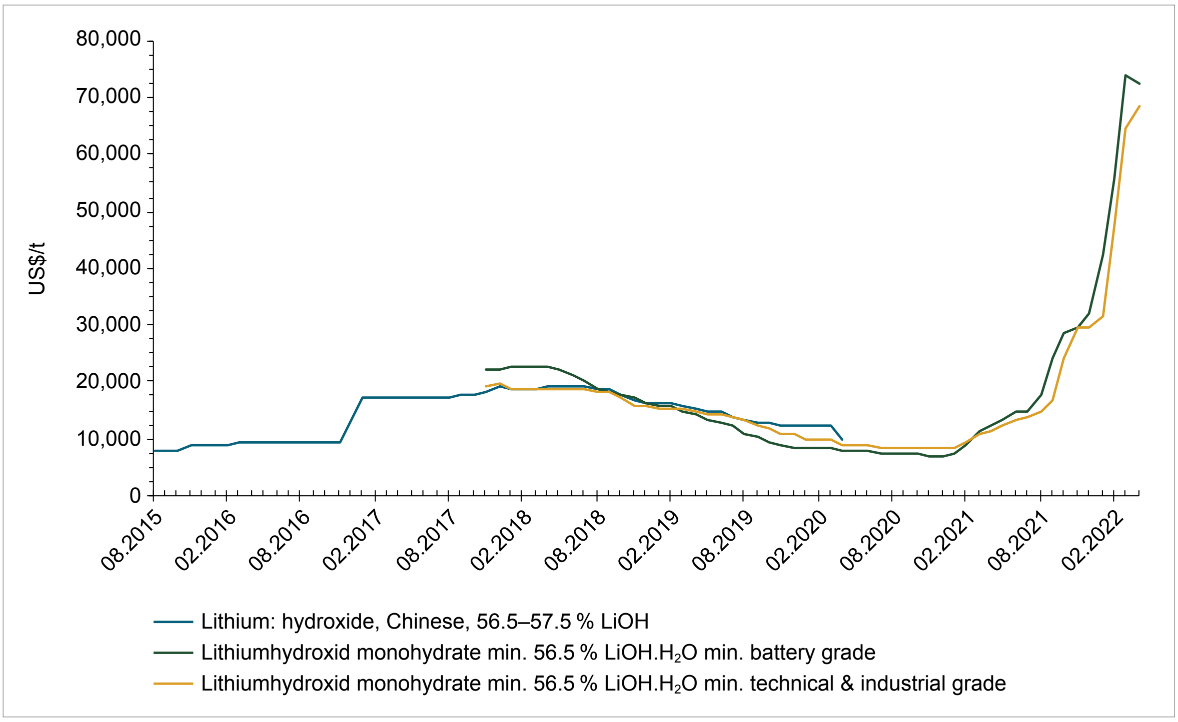

Fig. 4: Nominal prices for lithium hydroxide (08/2015–04/2022; data source: BGR 2022).

risen dramatically, reaching an absolute all-time high in April 2022 at around US$5,890/t. Within 18 months, the price rose by about 1,500 %, with an increase of 160 % since December 2021 (Fig. 5).

In addition to this time series for spodumene concentrate prices, price information is available for individual companies. Pilbara Minerals Ltd., for instance, sold spodumene concentrates

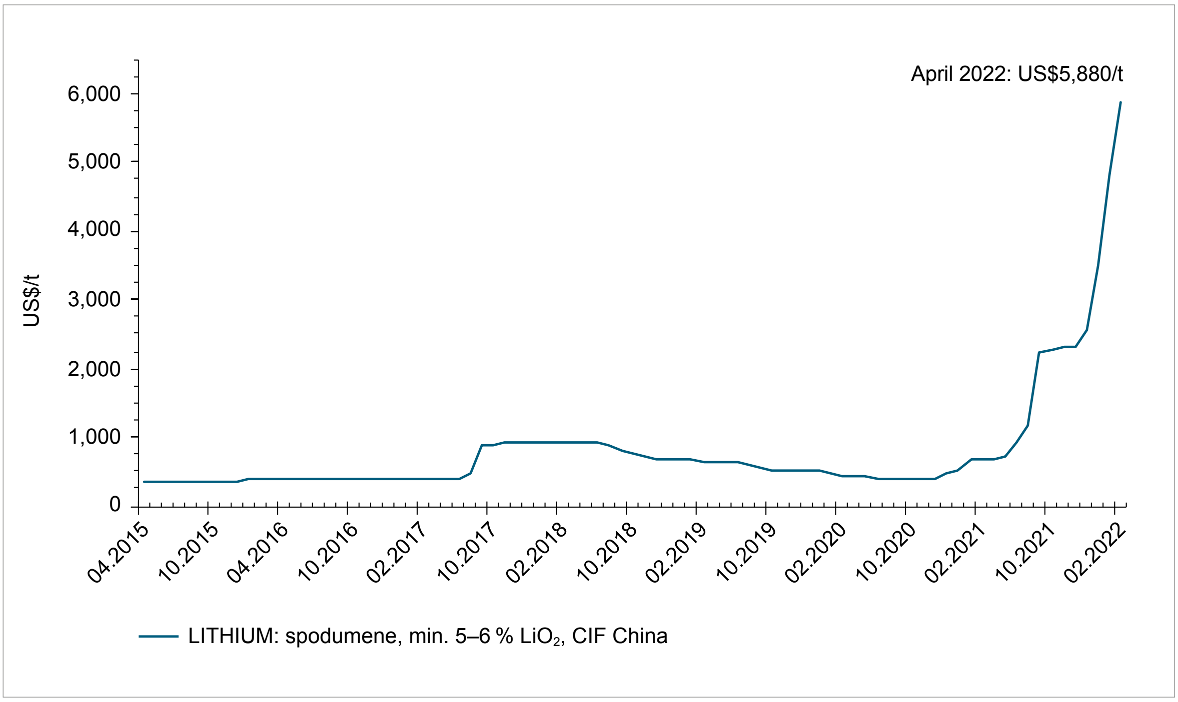

Fig. 5: Nominal prices for spodumene concentrates (04/2015–04/2022; data source: BGR 2022).

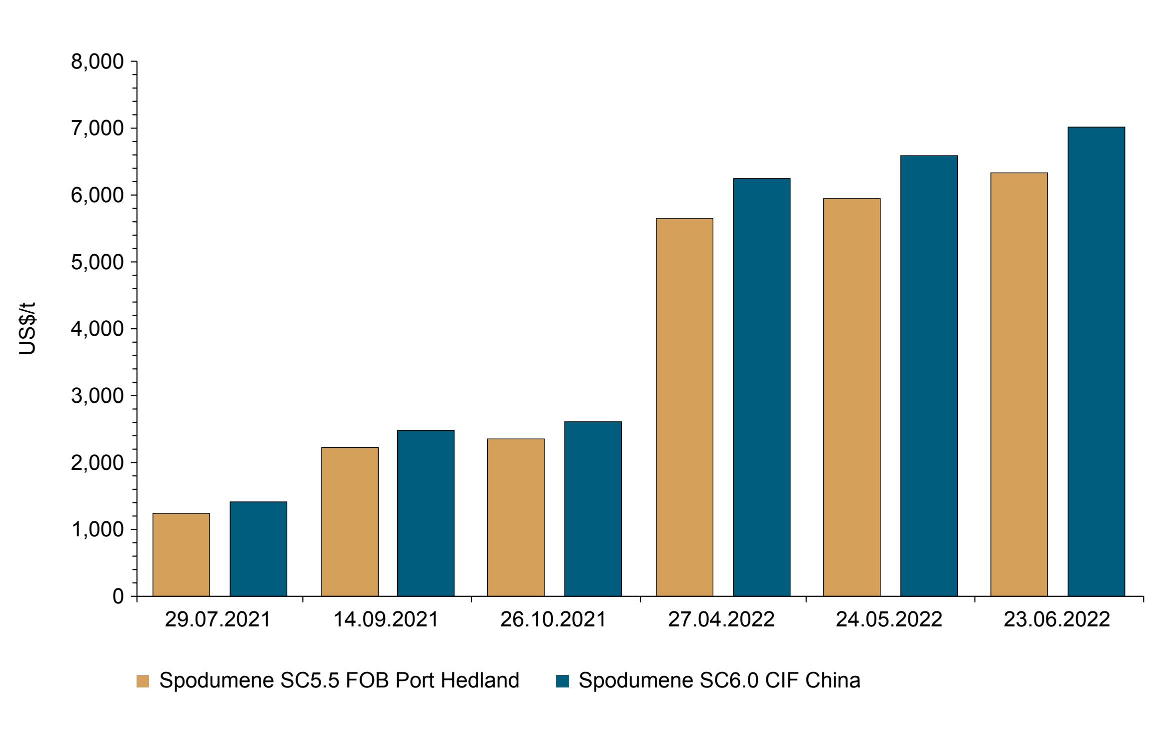

Fig. 6: Pilbara Minerals Ltd. price data for spodumene concentrate auctions (Pilbara BMX; data source: Pilbara Minerals 2022).

(SC5.5 FOB Port Hedland & SC6.0 CIF China) at its own Battery Material Exchange (BMX) in five auctions since August 2021. In each case, the amounts of concentrate were relatively small at 5,000 – 10,000 t. Whereas a price of around US$1,250/t for 5,000 t was achieved at the first auction in July 2021, this rose to US$5,955/t for 10,000 t in the fifth auction in May 2022 (S&P Global 2022). According to Pilbara Minerals Ltd., the sixth auction on 23 June 2022 achieved a record price of around US$6,350/t (SC5,5 FOB Port Hedland) for 5,000 t (Fig. 6). Further auctions are expected to be held in the course of 2022.

2.2 Supply

2.2.1 Lithium mining output

In 2020, global mining output of lithium (Li content) was around 82,120 t, or about 437,110 t lithium carbon equivalent (LCE; Table 7, Fig. 7). About 40 % of this was extracted from brine and 60 % from hard rock.

The most important producer country in 2020 was Australia with around 39,700 t of Li content (about 48.4 % market share), followed by Chile and China (Table 7). In fourth place but far behind was Argentina, formerly the third largest producer. Together, the four countries accounted for almost 98 % of global lithium output in 2020. The preliminary data for 2021 are almost 30 % higher than the 2020 figures (Table 7).

Table 8 shows the annual growth rates for global lithium output in selected time intervals. A detailed description of the period 1960 – 2015 can be found in Schmidt (2017).

From 1960 to 2020, global lithium mining output grew at an average annual rate (CAGR) of around 6.6 % (Table 8), equivalent to an increase of more than 4,600 % from around 1,741 t to a total of 82,117 t of Li content. The rise in global lithium mining output between 2015 and 2020 from around 33,000 t of Li content to about 82,000 t was due to the sharp surge in demand. It corresponds to a total increase of almost 150 % and an average annual growth rate of about 20 %. Particularly the major supplier countries Austra-

Table 7: Lithium mining output (data source: BGR 2022, S&P Global 2022, USGS 2022).

	Mining output [t Li cont.]						
Years	**2016**	**2017**	**2018**	**2019**	**2020**	**2021[5)]**	**Global share 2020 [%]**
Australia[1)]	15,590	47,513	58,800	45,000	39,700	55,000	48.4
Chile[2)]	14,526	16,584	17,000	19,300	21,500	26,000	26.2
China[3)]	4,775	6,832	7,100	10,800	13,300	14,000	16.2
Argentina[2)]	5,767	5,740	6,241	6,300	5,900	6,200	7.2
Brazil[1)]	195	250	430	530	620	1,500	0.6
USA[2)]	900	900	940	940	450	450	0.5
Zimbabwe[1)]	974	994	1,600	1,200	417	1,200	0.5
Portugal[1)]	299	763	230	230	230	900	0.3
Other countries[)]	18	588	2,933	490	0	0	0
Global output[)]	**43,044**	**80,164**	**95,274**	**84,790**	**82,117**	**105,250**	**100**
HHI	**2,763**	**4,069**	**4,239**	**3,556**	**3,338**		
GLR	**0.52**	**0.89**	**0.94**	**0.77**	**0.67**		

[1)] Lithium extraction from hard rock (pegmatites)
[2)] lithium extraction from brines
[3)] lithium extraction from brines and hard rock
[4)] slight deviations possible due to rounding
[5)] preliminary mining output data

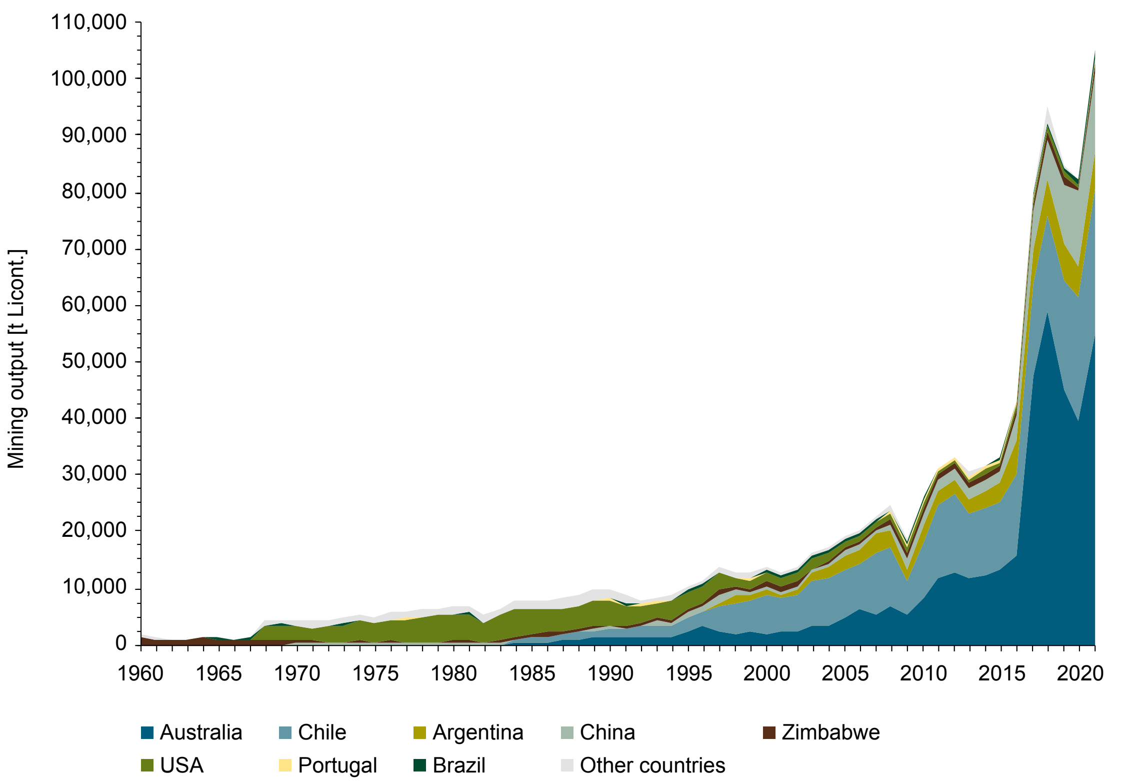

Fig. 7: Development of lithium mining output between 1960 and 2021 (data source: BGR 2022, S&P Global 2022, USGS 2022).*

** 2021 = preliminary mining output data*

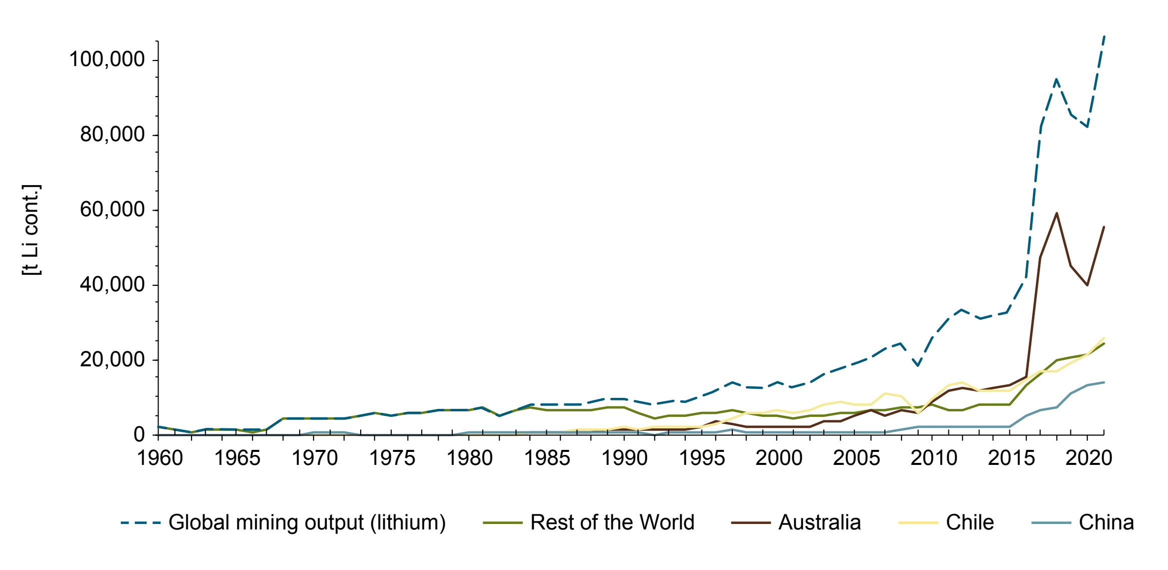

Fig. 8: Development of lithium mining output by Australia, Chile and China between 1960 and 2020 compared to the rest of the world (data source: BGR 2022, USGS 2022 S&P Global 2022).

lia, Chile and Argentina more than doubled their output. China, however, had the largest increase, with output rising from about 2,000 t to more than 13,000 t Li content (CAGR = 46 %). In less important producer countries for the market as a whole, such as Portugal, Zimbabwe or the United States, output fell during this period (Table 8), while Brazil recorded an increase. For 2021, a rise in output is forecast for Portugal, Zimbabwe, the United States and Brazil, thus leading to positive average annual growth rates.

Table 8: Annual growth rates for lithium output for selected time intervals from 1960.

	Annual growth rate CAGR [%]							
Period	**1960 –2020**	**1960 –1984**	**1984 –2020**	**1960 –2009**	**1984 –2009**	**2009 –2020**	**2010 –2020**	**2015 –2020**
Australia	21.7	32.9	14.8	22.2	12.7	19.7	16.7	24.7
Chile[1)]	–	–	11.8	–	11.2	13.0	8.3	12.8
Argentina	12.9	–5.6	27.3	13.9	36.3	8.9	6.4	10.9
China[1)]	–	–	11.3	–	8.3	18.7	21.7	46.0
Zimbabwe	–2.2	–5.2	–0.1	–0.9	3.4	–7.4	–7.6	–16.5
USA	15.1	57.0	–6.5	20.6	–6.4	–6.6	–7.6	–11.9
Portugal[1)]	–	–	19.8	–	33.0	–5.6	–6.8	–13.3
Brazil	8.8	6.2	10.5	9.7	13.1	4.8	5.4	27.2
Rest of the World[2)]	–	8.4	–	1.0	–5.6	–	–	–
World	**6.6**	**6.4**	**6.8**	**4.9**	**3.6**	**14.5**	**12.2**	**20.0**

[1)] No data available before 1984
[2)] comprises Canada, Namibia, Rwanda, Spain, South Africa, Surinam, Uganda, USSR/GUS
– no growth rates can be calculated for this period

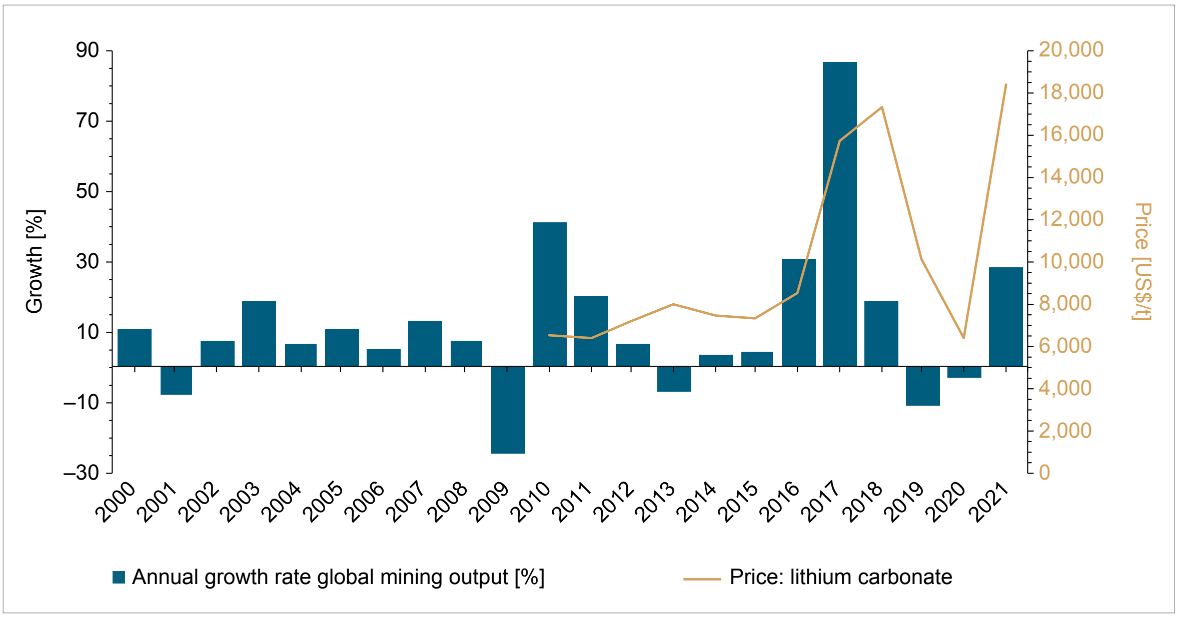

Fig. 9: Annual growth in lithium mining output in relation to nominal prices for lithium carbonate in the period 2000–2021 (data source: BGR 2022).

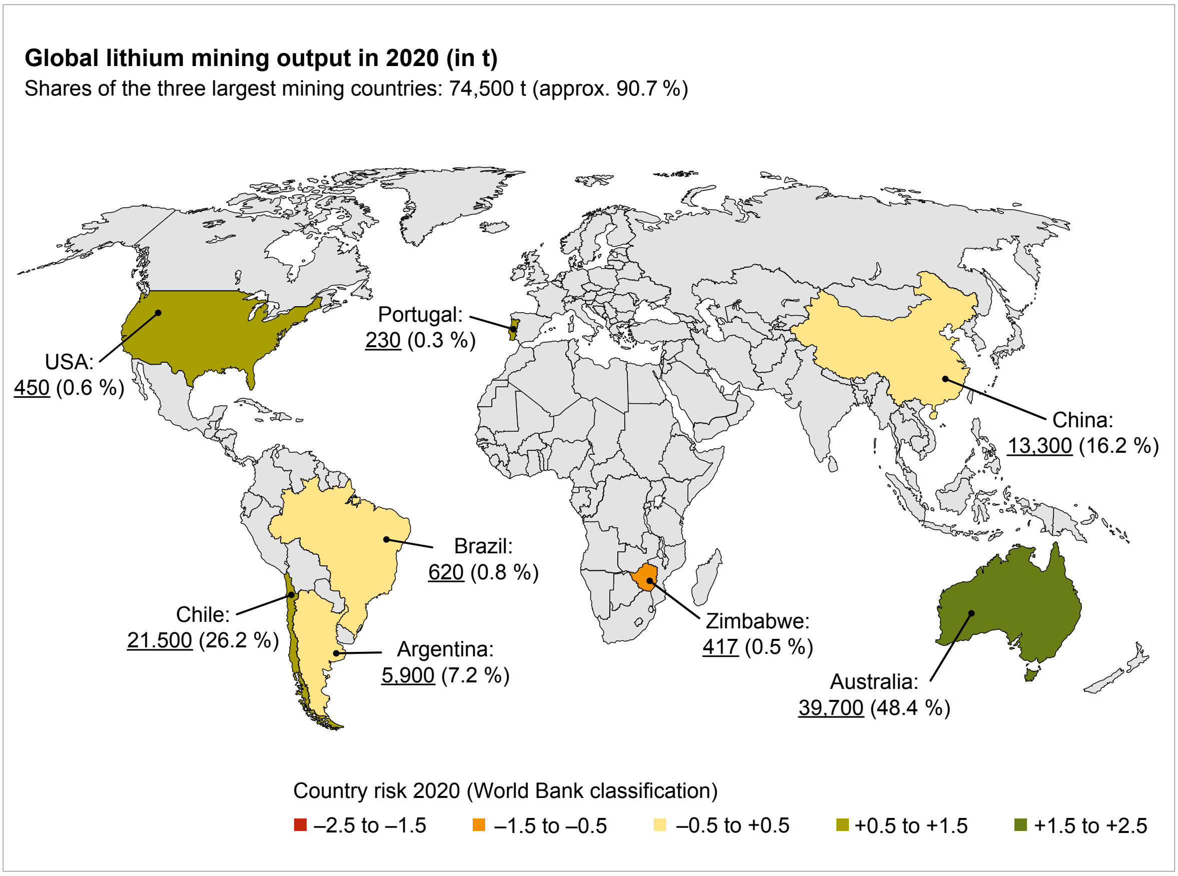

Fig. 10: Lithium-producing countries in 2020 and their aggregated World Governance Indicators (country risk; data source: BGR 2022, S&P Global 2022, USGS 2022, World Bank 2022).

2.2.1.1 Industry concentration

Unlike many other mineral resources, lithium is mined in relatively few countries and by few mining companies. Recent years have also seen strong momentum in strategic joint ventures (JVs), project partnerships and mergers. Chinese companies in particular have in the past few years been very active strategically at all levels of the value chain. This is true especially for Chengdu Tianqi Industry Grp Co. or Ganfeng Lithium Co. Ltd. among others. Albemarle and Chengdu Tianqi Industry Grp Co. are joint venture partners owning 49 % and 51 % respectively of the largest producer (Talison Lithium, Fig. 11). Chengdu Tianqi Industry Grp Co. also holds 23.8 % of shares in the Chilean company SQM S.A. (SQM 2022).

Generally speaking, lithium production is not part of the traditional mining sector such as copper or aluminium, but a branch of the chemical industry. Companies extracting lithium compounds from brines should therefore be considered vertically integrated enterprises. This form of vertical integration does not exist so far in companies producing lithium concentrates from hard rock, although there is a clear trend in that direction. Moreover, many companies collaborate in the two different process routes via strategic partnerships. It thus makes little sense to differentiate between primary production and processing at the company level.

Looking ahead to 2030 and beyond, new companies or spin-offs will enter the lithium market as actors, as was the case in recent years. The relatively young Australian enterprise Pilbara Minerals Ltd., for instance, already ranks 6th worldwide for output.

Table 9 shows the industry concentration in global lithium production for 2020. Of the global output of around 82,117 t of Li content, 94.3 % can be attributed to the individual companies based on their output figures (data from S&P GLOBAL 2022). The entire lithium production structure is oligopolistic, with the four largest producers together accounting for almost 64 % of global lithium output in 2020 and t The ten largest companies together accounted for around 89 % of the output.

The exercise of market power resulting from the global industry concentration of mining companies is considered uncritical based on a Herfindahl-Hirschman index (HHI) of approx. 1,206 (Fig. 11). Since 2015, the level of concentration has significantly changed (2015 top 5: 91 %, HHI: 2,480). Taking into account the individual JV shares (Table 9) would theoretically reduce the HHI to 1,112, which is also in the uncritical range.

In future, industry concentration can be expected to increase. Pilbara Minerals, for instance, took over the project of neighbouring Morella Corp. (formerly Altura Mining; AUSTRALIAN MINING 2022) in 2021. From 2021 or from the start of production, output will therefore be listed under Pilbara Minerals. Galaxy Resources was incorporated into Allkem in 2021, so its output will in future be aggregated under Allkem.

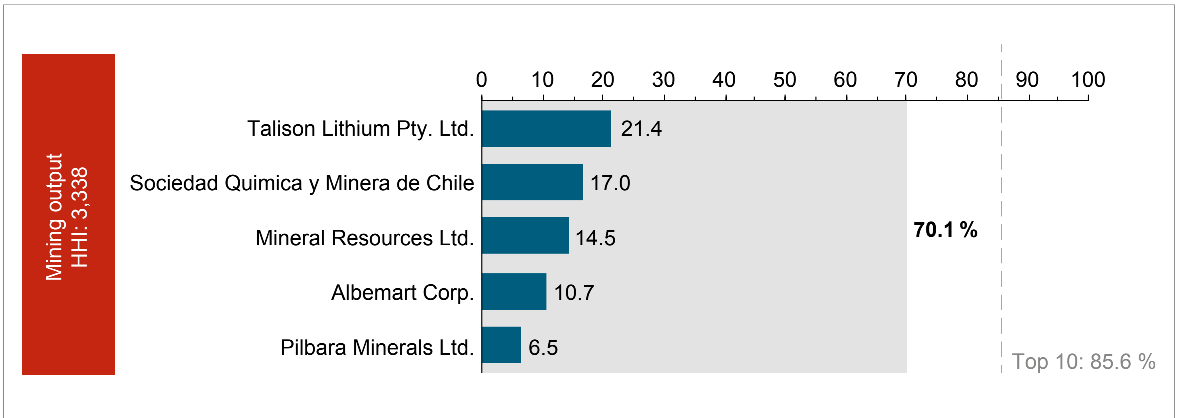

Fig. 11: Industry concentration in lithium mining for 2020 (S&P GLOBAL 2022).

Table 9: Shares of the largest companies in lithium mining output (data source: BGR 2022, S&P Global 2022).

Company	Domicile	Mining country	2020 [t Li cont.]	Share [%]	2020 [t Li cont.]	Share [%]
			excl. JV shares (operator)		incl. JV shares	
Talison Lithium Pty. Ltd.[1)]	Australia	AUS	~ 16,530	**21.4**	0	0
SQM S.A.	Chile	CHL	~ 13,151	**17.0**	13,151	**17**
Mineral Resources Ltd.[2)]	Australia	AUS	~ 11,240	**14.5**	5,620	7.3
Albermarle Co.[1)]	USA	CHL, AUS	~ 8,304	**10.7**	16,404	**21.2**
Pilbara Minerals Ltd.	Australia	AUS	~ 5,041	**6.5**	~ 5,041	**6.5**
Chengdu Tianqi Industry Grp Co.[1)]	China	CN, (AUS)	0	**0**	8,431	**10.9**
Ganfeng Lithium Co. Ltd.[3)]	China	CN, (AUS, ARG)	0	**0**	6,847	**8.8**
Livent Corp[4)]	USA	ARG	~ 3,720	4.8	~ 3,720	4.8
Galaxy Resources[5)] Ltd.	AUS	AUS	3,001	**3.9**	3,001	3.9
Morella[6)] Corp.	Australia	AUS	2,653	3.4	2,653	3.4
Lithium Americas Corp.[7)]	Argentina	ARG	2,630	3.4	1,179	1.5
Qinghai Salt Lake Industry Co.			2,537	3.3	2,537	3.3
Yichun Tantalum Co Ltd.	China	CN	1,839	2.4	1,839	2.4
Western Mining Group Co. Ltd.			1,776	2.3	1,776	2.3
Allkem[8)] Ltd.	Australia	AUS, ARG	1,606	2.1	1,068	1.4
Bikita Minerals Ltd.	Zimbabwe	ZIM	1,561	2.0	1,561	2.0
Qinghai Hengxin Rongliye Tech.	China	CN	633	0.8	633	0.8
Toyota Tsusho Corp.[9)]	Japan	JP, (ARG)	0	0	402	< 0.5
Jujuy Energia y Mineria[10)]	Argentina	ARG	0	0	360	< 0.5
AMG Advanced Metallurgical Grp.	Brazil	BRA	356	< 0.5	356	< 0.5
Cia Brasileira de Litio	Brazil	BRA	267	< 0.3	267	< 0.3
Grupo Mota	Portugal	PRT	232	< 0.3	232	< 0.3
Youngy Invt. Hldg. Grp. Co. Ltd.			172	< 0.2	172	< 0.2
Tibet Zangge Venture Cap Grp.	China	CN	100	< 0.1	100	< 0.1
Sichuan Yonghong Industrial Co.			37	< 0.1	37	< 0.1
Beijing Lianzhong Peer Biotech			6	< 0.1	6	< 0.1

Company	Domicile	Mining country	2020 [t Li cont.]	Share [%]	2020 [t Li cont.]	Share [%]
			excl. JV shares (operator)		incl. JV shares	
Qinghai Zhonghao Natural Gas Co.	China	CN	1.5	< 0.1	1.5	< 0.1
Xinjiang Huajing Junhua Eqty.			1	< 0.1	1	< 0.1
Beijing Lianda Sifang Invt. Con.			1	< 0.1	1	< 0.1
Total[11)]:			**~ 77,397**	**94.3**	**~ 77,397**	**94.3**
HHI[11)]:			**1,206**		**1,112**	
Other companies and countries[11)]			4,720	5.7	4,720	5.7
Global mining output[11)]:			**~ 82,117**		**~ 82,117**	

1) Greenbushes JV between Albemarle and Lithium HoldCo (Tianqi Lithium Co.Ltd./IGO)
2) Mt Marion as a JV between Mineral Resources and Ganfeng Lithium
3) Mt Marion as a JV between Mineral Resources and Ganfeng Lithium; Cauchari-Olarioz as a JV between Ganfeng Lithium and Lithium Americas
4) spun off from FMC and renamed
5) integrated in Allkem from 2021
6) Altura project by Morella Corp. (formerly Altura) taken over in 2021 by Pilbara Minerals
7) Cauchari-Olarioz as a JV between Ganfeng Lithium, Lithium Americas and Jujuy Energia y Mineria
8) Allkem as a 2021 spin-off from Orocobre and integration of Galaxy Resources in 2021. Olaroz project as a JV between Allkem, Toyota Tsuho and Jujuy Energia y Mineria
9) JV shares in Olaroz
10) JV shares in Olaroz and Cauchari-Olaroz
11) slight deviations possible due to rounding

2.2.2 Country concentration and weighted country risk in production

Country concentration in lithium mining

Since the early 1980s, Chile and Australia have consistently increased their lithium output, becoming the largest mining countries for lithium today. For Australia in particular this applies since 2015. In the same period, the formerly dominant role of the United States declined.

With a Herfindahl-Hirschman index (HHI)[1] of just over 3,300, the country concentration in global lithium mining is in a critical range (Table 7). In historical terms, the HHI for global mining fell between 1960 and 2020 from just under 8,000 to 3,338. The main reason is a decline in mining in the United States and Zimbabwe and the simultaneous strong increase in Australia, Chile, Argentina and China (Fig. 7, Fig. 8). Fig. 12 shows the development of the country concentration over time.

Weighted country risk in lithium mining output

Based on the Worldwide Governance Indicators of the World Bank (World Bank 2022) and mining output figures, the weighted country risk (WCR, see glossary) for lithium mining output was in the uncritical range in 2020, with a value of 0.67[2]. Compared to 2015 (WCR = 0.95), however, it has deteriorated significantly (Fig. 10, Fig. 12).

With a risk rating of 1.48, Australia is considered a very low-risk country. Because of its high percentage share in output (48.4 %), it is thus a major factor in the WCR. The same applies to Chile (26.2 % share), also rated low-risk with a rating of

[1] The level of concentration is calculated based on the Herfindahl-Hirschman index (HHI, see appendix). HHI values between 1,500 and 2,500 are rated as moderate risk, values > 2,500 are considered critical. This index also applies to industry concentration (U.S. Department of Justice 2010).

[2] Based on the World Bank scale for country risk (ranging from –2.5 to 2.5), countries with a risk of between 0.5 and –0.5 are rated as moderate risk. Values < –0.5 are rated as critical. This scale is also used for the weighted country risk (WCR).

0.89. These two countries determine the WCR to a large extent. China and Argentina, the third and fourth largest producer countries, are considered as moderate risk, with ratings of –0.25 and –0.12 respectively, and thus have a negative impact on the WCR.

Overall assessment of mining

As in 2015, the country concentration in lithium mining remains in the critical range. Although the weighted country risk is uncritical, it has deteriorated significantly. Overall, the geopolitical risk of global mining is considered as moderately critical. But while the current supply situation appears uncritical, a significant deterioration can be expected when a lack of deliveries arises, because of China's market dominance.

Australia and Chile have over the past decades proved to be reliable supplier countries. Both countries together supplied almost 76 % of global lithium output in 2020. Political developments in Chile and the planned restructuring of the Chilean lithium industry must be monitored, however, since they could have a major impact on the country's future productive capacities.

Political developments in other countries could also affect future supply. Mexico, for instance, adopted a reform of its mining code in April 2022, resulting in the foundation of a state-owned lithium company (LitioMX, Litio para Mexico), which will in future be responsible for all lithium production and sales. Existing contracts will be reviewed for validity by LitioMX (Handelsblatt 2022).

The same applies to the considerable resources in Bolivia. To date, there is no domestic industrial-scale production and all projects of the recent past have been stopped for various reasons. Currently, the Bolivian government is pursuing a new approach to develop a lithium industry. In a tender, six companies were selected as possible candidates for a joint venture with YLB (Yacimientos de Litio Bolivianos) at the Salar de Uyuni (Reuters 06/2022). The final decision was postponed to December 2022.

Political developments in Serbia also need to be monitored closely. It is currently impossible to say whether the Rio Tinto mining company will be able to continue the development of the important Jadar project for lithium and boron, nor at what point in time and in what scope. Because of its size, the project would be of major importance as a potential supplier to the European market.

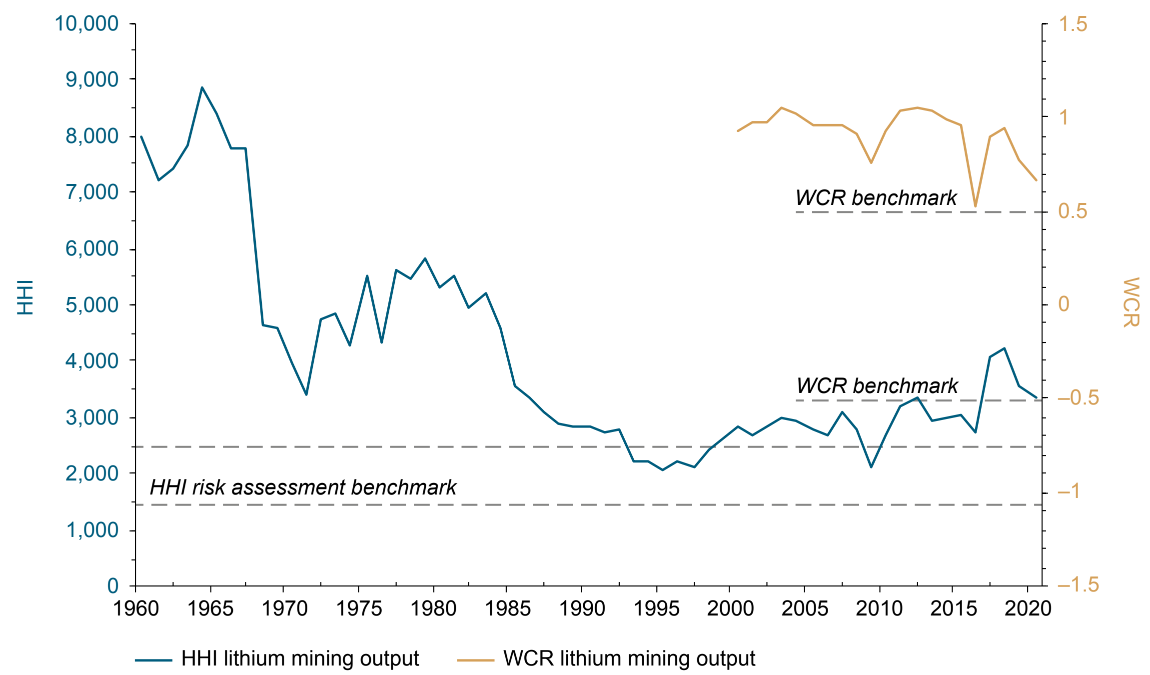

Fig. 12: Development of country concentration and the weighted country risk of lithium mining (1960–2020).

2.2.3 Recycling

Recycling and thus the supply of secondary lithium has to date played only a minor role for the global lithium supply. That is going to change significantly by 2030 and particularly after that.

The largest lithium recycling potential is from rechargeable lithium-ion batteries (LIBs). Particularly the recycling of batteries from electric vehicles will in future play a major role, even more so because this drive technology is supposed to be sustainable and environmentally sound. But this will only be successful if there is a closed or partly closed cycle of production (design for recycling), initial use, reuse and recovery of these batteries. Reasons for the low share of recycling at present are modest return rates, large primary lithium resources/reserves, and the relatively low-cost primary production of this raw material (Martin et al. 2017). Other major factors in this context are the dissipative distribution of lithium, complex technological requirements of the recycling processes, and the technological purity requirements of specific applications in end products. Schmidt (2017) discusses the basic process routes for battery recycling in detail.

As a general rule, the use, disposal and recycling of LIBs are subject to the EU's Batteries Directive. A new proposed Directive has been adapted from the 2006 Directive (2006/66/EC) to meet current challenges. It is expected to specify labelling rules, information obligations and supply-chain due diligence standards, as well as requiring metal-specific recycling rates and the use of recycled content in batteries with a capacity above 2 kWh. This applies primarily to batteries used in electric vehicles. For the first time, information on the carbon footprint of battery production will also have to be stated. Proposed in 2019, the new Directive could take effect in 2023 (Fig. 13).

The aims specified in the new Batteries Directive concern the recycled content and recovery rates for certain metals, such as cobalt, nickel or lithium. Within the EU, the share of lithium from recycling in new LIBs is to increase to 4 % in January 2030, with a recycling rate of 70 %, and further from 4 % to 10 % in 2035 (Ec 2020).

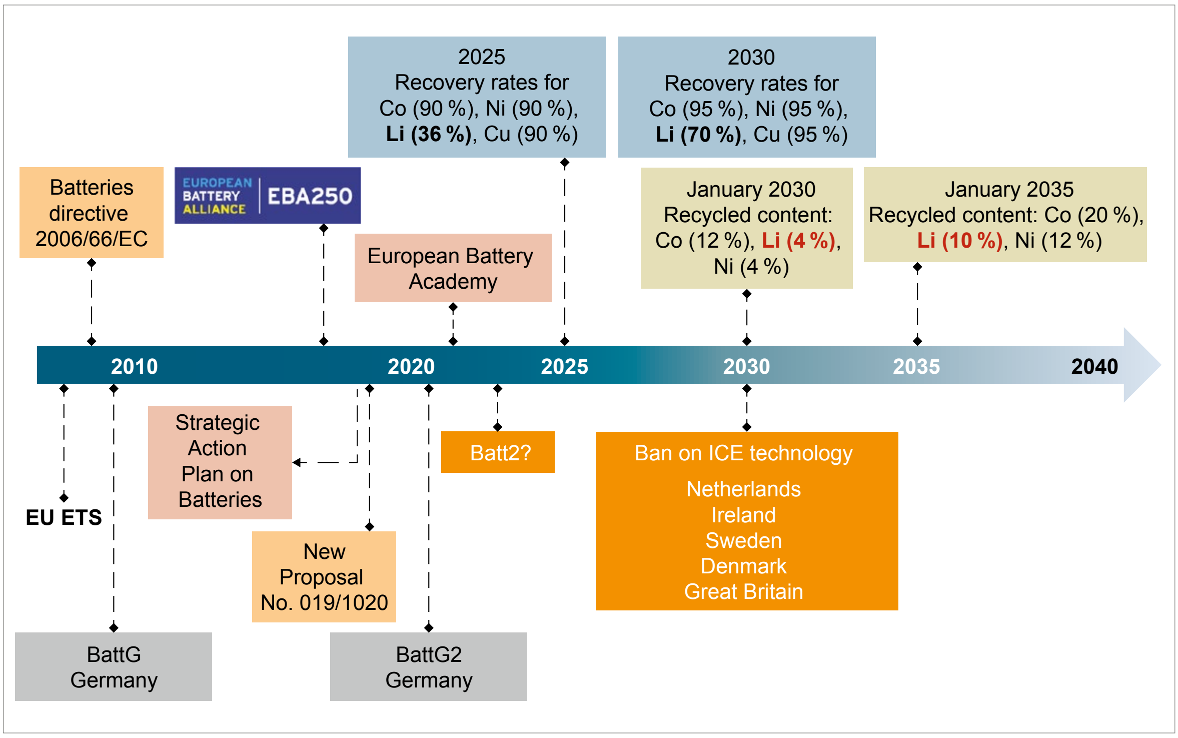

Fig. 13: Development of the legal framework since the introduction of the EU's Batteries Directive in 2006 (Kresse et al. 2022).

Lithium-ion batteries

Taking into account the lifespan and potential reuse of batteries, recycling will become a major part of the raw material cycle. Factors to be considered are product lifespans, potential reuse and thus a delay before recovery, and losses during the recycling process. Section 2.6.3.2 contains calculations on the supply of secondary lithium carried out by DERA

The European market for LIB recycling is at an early stage with a large potential for growth. Among the established industrial recycling facilities in Germany and Europe with an annual capacity of > 2,000 t of batteries are Umicore, Accurec, Nickelhütte Aue, AkkuSer and Duesenfeld. Pilot plants with an annual recycling capacity of < 2,000 t include TEM, SNAM, Volkswagen and Primobius (Kresse et al. 2022).

Lithium-ion batteries are generally a difficult feedstock for the recycling plant process, particularly with regard to corrosion, fire risk, slag properties, and their energy and mass balances. According to information in the patent originating from the LiBRi research project, a total lithium recovery rate of around 90 % from slag could be achieved, which is comparable to the yield from spodumene concentrates (Brückner et al. 2020).

To permit future economic operation in this dynamic sector, recycling processes for LIBs must meet parameters such as scalable plant capacities and openness to technological innovation. The recycling processes used by Umicore, Accurec and Duesenfeld are described in Kresse et al. (2022).

Other applications

Lithium used in ceramics and glass-ceramics is not recovered. But cullet can be recycled, provided it is correctly sorted. In lubricants, lithium is used in the form of chemical compounds (additives). While there is no recovery of these compounds or of lithium, lubricants such as oil or grease can generally be reprocessed and reused. Oils are purified to remove contaminants, more additives are incorporated and the reprocessed oil can then be reused. The contaminated waste is disposed of in landfill (Roskill 2016).

2.3 Demand

At present, total lithium demand is still met by the primary supply from mining, with the secondary sector taking only a minor role. This is going to change significantly from 2030 and beyond.

Because of its very specific properties, lithium is used in many products (Schmidt 2017). In 2020, total demand amounted to around 73,600 t of Li content (391,800 t LCE; Fig. 14) according to CRU (2022), an increase of about 116 % from 2015 (approx. 34,000 t Li content).

Demand by area of application

In 2020 as in 2015, rechargeable batteries, ceramics/glass-ceramics/glass (cumulative) and lubricants accounted for most of the demand (Fig. 14).

Rechargeable batteries: Demand for lithium for rechargeable batteries has continuously increased over the past few years. While this area accounted for around 58,400 t LCE or about 32.3 % of total demand in 2015, it had risen to about 262,100 t LCE or almost 67 % of total demand by 2020 (Fig. 14). That corresponds to an increase of about 350 % within five years. Within the area of rechargeable batteries, there are the segments 3C, power and motive, ESS and e-mobility. The e-mobility segment (LDV, HDV, buses) accounted for almost 41 % of demand for rechargeable batteries in 2020, and 3C applications for around 37 % (CRU 2022).

Ceramics/glass-ceramics/glass: This industry is still the second largest area of application for lithium, but with only little annual growth. In 2020, demand was around 64,000 t LCE, only about 6 % higher than in 2015 (60,000 t LCE) and equivalent to a share in total demand of only around 16.3 %.

Lubricants: Lubricants, an area where lithium is used as an additive, are the third largest lithium market. In 2015, demand was around 19,000 t LCE (10.6 % share), while in 2020 it amounted to just 6 % more, about 20,300 t LCE, which represented only 5.2 % of the total market.

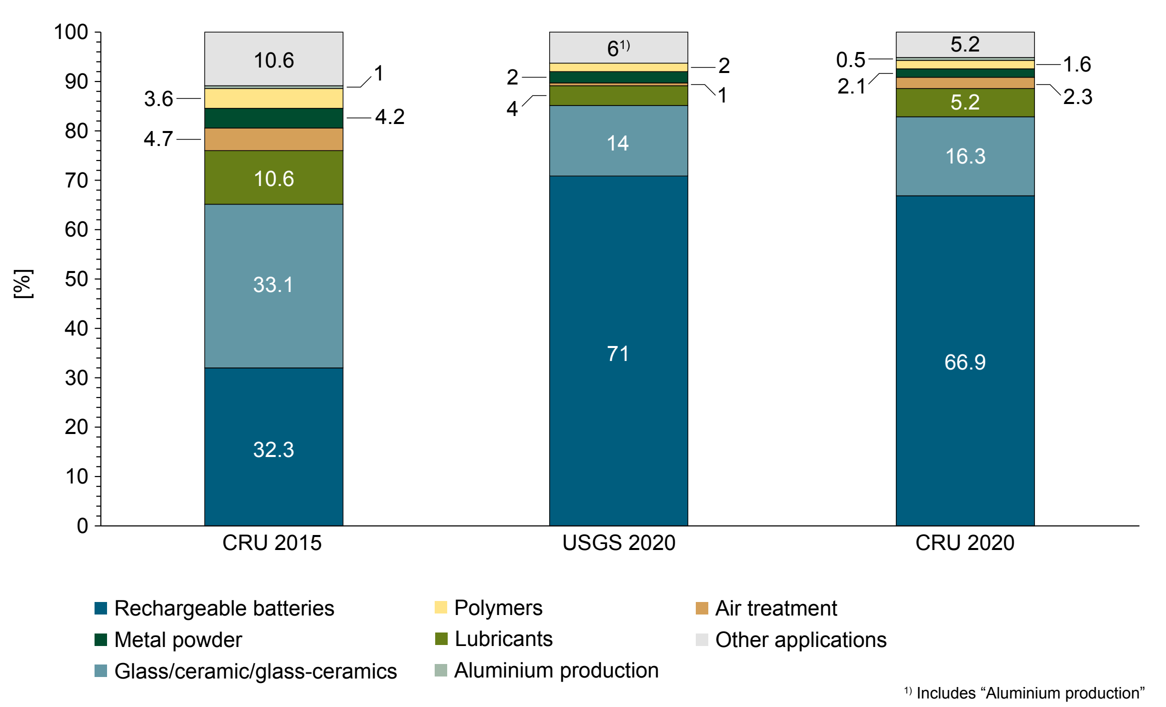

Fig. 14: Comparison of total global demand by area of application in 2015 and 2020 (data source: Roskill 2016, USGS 2022, CRU 2022).

"Other applications" comprises these areas:

Air treatment
approx. 9,000 t LCE; global share: 2.3 %; +7.0 % on 2015

Metal powder
approx. 8,270 t LCE; global share: 2.1 %; +9.4 % on 2015

Polymers
approx. 6,100 t LCE; global share: 1.6 %; –6.0 % on 2015

Aluminium production
approx. 2,000 t LCE; global share: 0.5 %; +13.5 % on 2015

Other applications
approx. 20,250 t LCE; global share: 5.2 %; +6.1 % on 2015

2.4 Current supply/demand balance

This discussion of the current supply/demand balance is based on demand data from Roskill (2016) for the period 2010–2015 and supply and demand data from CRU (2022) for the period 2015–2020. The supply/demand balance expresses the ratio of supply (output) to demand (consumption) as a percentage.

The relatively low deficit in 2015 grew to around 2,300 t Li content (–6.5 %) in 2016. In 2017 and even more so in 2018, primary production increased, partly because new mines had been commissioned. At the same time, demand was lower than expected, resulting in a considerable excess supply and the stockpiling of concentrates, particularly in China. In 2017 and 2018, excess supply amounted to around 5,000 t Li content (10 %) and 13,800 t Li content (21.6 %) respectively (Fig. 15). A similar situation had arisen earlier, in 2011 and 2012.

Despite the excess supply, prices rose sharply between 2016 and mid- to late 2018. The reason for this was the value chain of the lithium industry, supplying to a specialist market for chemicals. An excess in primary output, such as of concentrates, does not necessarily mean that lithium carbonate and/or hydroxide are available on the market in the required qualities and particularly quantities.

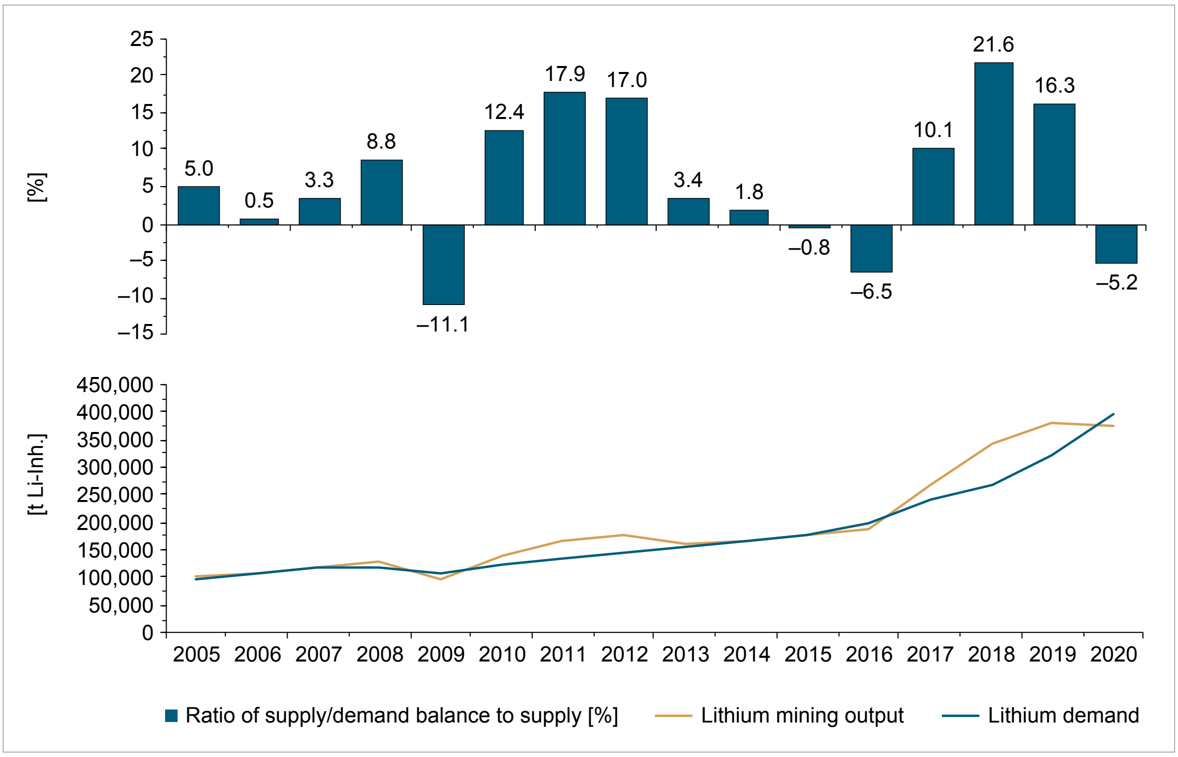

Fig. 15: Lithium supply/demand balance: development of mining output and demand from 2010 (data source: Roskill 2016, CRU 2022).

Processing thus became the industry bottleneck during this period.

In 2019 and 2020, falling demand and thus a drop in prices resulted in productive capacities being scaled down. Some mines were even temporarily closed and stockpiles were reduced. The surplus still amounted to almost 12,000 t Li content (16.30 %) in 2019. A massive surge in demand in the second half of 2020, however, swung the market into a deficit of 3,700 t Li content (–5.2 %; Fig. 15). By 2021, demand exceeded supply by 8,400 t Li content (10 %).

2.5 Trade

Data on the global lithium trade are available for the specifications listed in Table 10. The product groups lithium carbonate and lithium hydroxides/lithium oxides are the most important global lithium commodities.

Table 10: Commodity groups according to the Harmonised System (HS) of the World Customs Organisation (WCO 2022) for lithium and lithium products (data source: IHS Markit 2022).

Trade name	HS commodity code[1)]
Lithium carbonate	2836.91
Lithium oxide and lithium hydroxide	2825.20
Lithium chloride[2)]	2827.30.xx[2)]
Mineral concentrates[3)]	2530.90.xx[3)]
Lithium-ionen batteries	8507.60

[1)] HS = Harmonised System of the World Customs Organisation (WCO);
[2)] commodity group created based on the 8-digit commodity codes for Chile, Argentina and China
[3)] based on HS group 2530.90.93; change in the Australian HS from 2530.90.93 (until 12/2020) to 2530.90.11 (from 01/2021)

The trade in lithium carbonate (HS 2836.91) can be fully broken down by country. This is not possible for lithium oxide and lithium hydroxide (HS 2825.20), which are subsumed under one HS commodity code. Considering the two products separately by country is thus not an option, although lithium hydroxide probably accounts for the larger share.

Lithium chloride is classified together with other commodities in one HS group (2827.30) and trade can therefore only be broken down based on the (8-digit) country-specific commodity codes. These are available for the major export countries Argentina, Chile and China. With some countries not included, trade movements may not be fully captured. Argentina and Chile are nevertheless the largest exporters.

The situation is similar for spodumene concentrates, which are classified in commodity group 2530.90 together with other mineral resources. Australia's specific 8-digit country codes (HS 2530.90.93 and HS 2530.90.11) were therefore used to capture trade. Since Australia itself does not import spodumene concentrates, its exports correspond to its net exports. Brazil is the only other country with a specific commodity code for lithium mineral concentrates (HS 2530.90.93). Zimbabwe as a producer of lithium mineral concentrates (petalite) does not give figures for exports, and they were therefore calculated on the basis of global imports: the country does not import concentrates and the calculated exports are therefore net exports. No other import countries can be identified due to the lack of HS commodity groups, which is why the trade figures specified here are based only on Australia, Brazil and Zimbabwe.

While small quantities of lithium metal and lithium brines are also traded, no HS commodity codes are available for this trade, which can therefore not be captured.

The data specified here refer to the positive net exports (NX > 0) of each HS commodity group, since the focus is primarily on the supply side (see the glossary in the appendix).

2.5.1 Net exports

Asia, and in particular China, plays a key role in the entire lithium value chain. The country is, for instance, the world's largest exporter of the end product, lithium-ion batteries (Table 11). For the manufacture of LIBs, China needs to import or

Table 11: Net exports of the most important lithium products in 2021 (data source: IHS Markit 2022).

HS commodity code	Global exports [kt]	Global imports [kt]	NX > 0 [kt]	Largest net exporters	HHI net exports	GLR net exports
2836.91	~ 334.2	~ 195.4	~ 165	CL (81.3 %) ARG (18.5 %) BE (0.2 %)	6,948	0.7
2825.20	~ 114.7	~ 113.2	~ 102.5	CN (68.3 %) CL (11 %) BE (0.4 %)	4,914	0.05
2827.30.xx[1)]	~ 0.6	~ 0.2	~ 0.4	CN (62.8 %) ARG (37.2 %)	5,327	–0.2
2530.90.xx[2)]	~ 2,146[2)]	n/a	~ 2,146	AUS (94 %) BRA (4.8 %) ZIM (1.2 %)	8,855	1.37
8507.60[3)]	~ 8.3 Mrd. Stk.	~ 5.6 Mrd. Stk.	~ 4.6 Mrd. Stk.	CN (40.9 %) JP (21.3 %) KOR (16.1 %)	2,575	0.51

1) Commodity group created based on the 8-digit commodity codes for Chile, Argentina and China
2) based on HS group 2530.90.93; change in the Australian HS from 2530.90.93 (until 12/2020) to 2530.90.11 (from 01/2021); includes data for Australia, Brazil and Zimbabwe; incomplete due to lack of HS classification of other countries
3) in units.

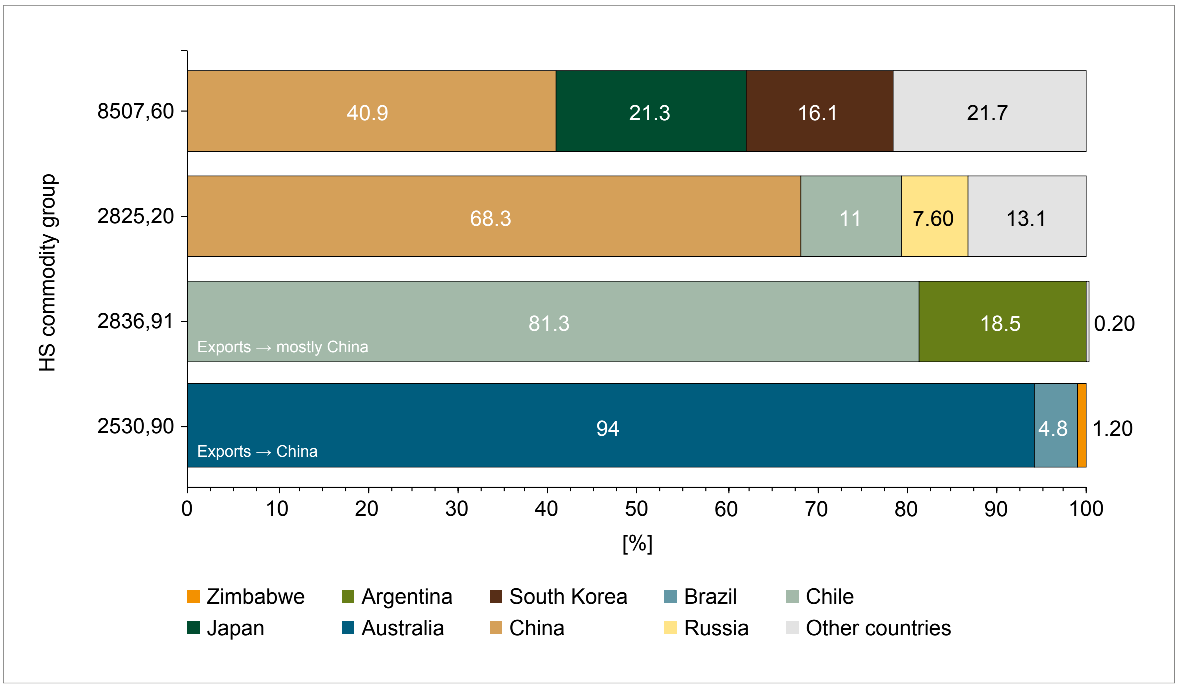

Fig. 16: Net exporters of the most important lithium products in 2021 (data source: IHS Markit 2022).

locally produce major battery raw materials, i.e. lithium compounds.

Lithium and lithium compounds are produced via two main process routes (Fig. 1). In South America, lithium carbonate and lithium hydroxide are produced directly from brine deposits and exported (see appendix).

In 2021, China was by far the largest global importer of lithium carbonate (41.5 %) and also the largest exporter (32.4 %). Its exports comprise domestic production and transit trade.

China was only the third largest importer of lithium hydroxide (3.2 %) but the world's largest exporter with around 68.3 %. For the production of lithium hydroxide, China relies on local deposits but mainly on imports of spodumene concentrates from Australia (see appendix). Lithium hydroxide then enters the local value chain or is exported, to South Korea or Japan, for instance.

This dominant position could change in future, as some countries and companies are increasingly driving the development of local value chains.

2.5.1.1 Country concentration and weighted country risk for net exports

Lithium carbonate (HS code 2836.91)

The country concentration for net exports of this commodity group calculated for 2021 using the Herfindahl-Hirschman index (HHI) was 6,948 and thus in the critical range. This was a slight increase of both the HHI and the country concentration compared to 2015 (6,486). The weighted country risk (WCR) is 0.70, which can be considered uncritical.

Overall, only three countries emerge as net exporters, with the two largest accounting for 99.8 % of exports. Belgium as a transshipment location plays only a minor role, while the two most important countries are Chile (81.3 %) and Argentina (18.5 %). This situation will not change significantly, because new productive capacities are focused more on lithium hydroxide (see below).

Lithium hydroxide and lithium oxide (HS code 2825.20)

This commodity group comprises lithium hydroxide and lithium oxide, although trade predominantly concerns lithium hydroxide. With an HHI of 4,914, the concentration of exports is in the critical range. Since 2015 (HHI 3,200), country concentration has grown considerably. The weighted country risk (WCR) is 0.05, which can be considered moderately critical. It has thus deteriorated significantly since 2015, because of China's share of the supply. The two most important countries are China (68.3 %) and Chile (11 %).

The future trend will be for this situation to change considerably, with productive capacities for lithium hydroxide being developed mostly in Australia. With the planned expansions, the Kwinana and Kemerton plants alone will produce roughly up to 100,000 t of lithium hydroxide. Since this scope exceeds demand in Australia, the material will be exported, making Australia a future net exporter. To put this into context, the largest net exporter at present, China, supplied around 70,000 t in 2021. With local value chains and vertical integration, additional supplier countries will also enter this market.

Lithium chloride (HS code 2827.39.xx)

Based on the calculated trade data, export concentration for 2021 was clearly in the critical range, with an HHI of around 5,330 and only slightly below 2015 (HHI 5,930). The weighted country risk (WCR) is –0.20, which can be considered moderately critical. Compared to 2015, the WCR has significantly deteriorated.

Mineral concentrates (HS code 2530.90.xx)

Since lithium mineral concentrates are combined with other products in commodity group 2530.90, there are insufficient data to give a quantitative assessment of net exports. However, only Australia and Brazil list specific HS-based commodity codes for these products.

Taking the calculated export figures as a basis, an HHI of around 8,855 results for 2021. Country concentration is only slightly higher than in 2015 (HHI 8,830). The weighted country risk of 1.37 can be considered uncritical, due to the positive country assessment for Australia in combination with its large net export shares. However, with coun-

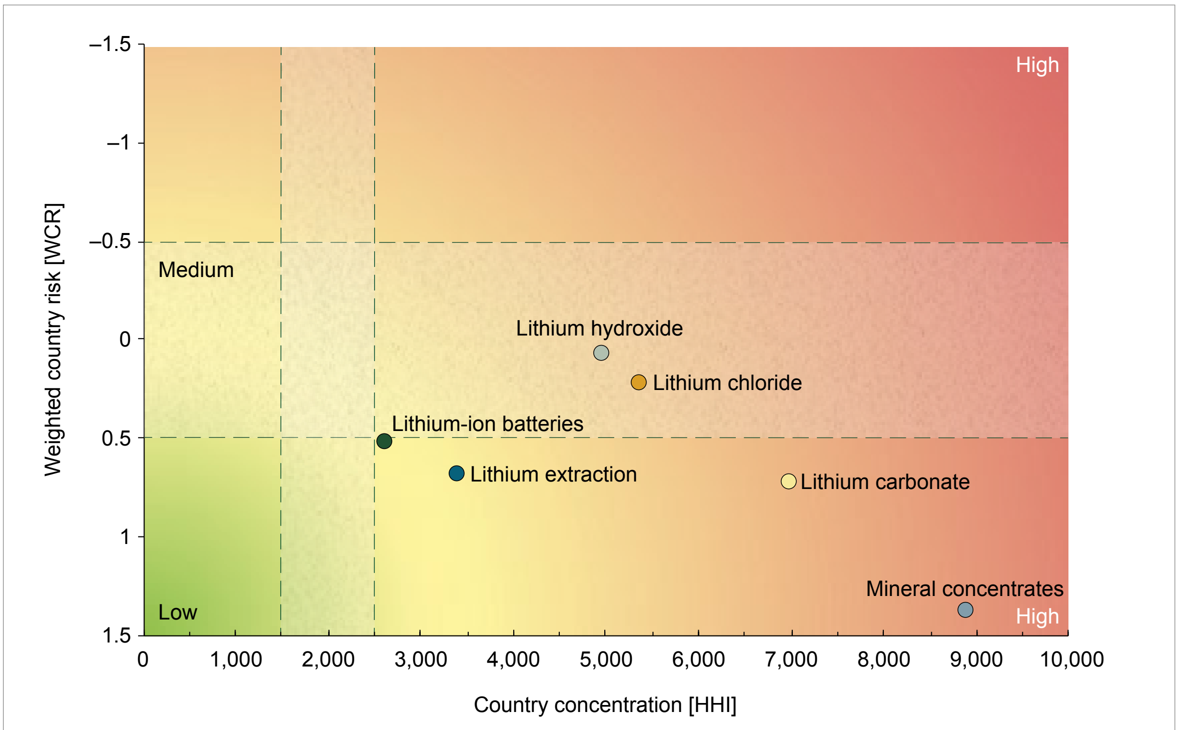

Fig. 17: Country concentration and weighted country risk of global positive net exports compared to lithium mining output (data source: BGR 2022, IHS Markit 2022).

tries such as DR Congo, Mali, Canada, the United States, Brazil and some European states developing their capacities, country concentration could decline despite the continued enormous increase in productive capacity in Australia.

Lithium-ion batteries (HS code 8507.60)

The level of concentration of lithium-ion battery exports in 2021 was just within the critical range, with an HHI of 2,575. Country concentration fell considerably compared to 2015 (HHI 4,353). The weighted country risk (WCR) is 0.51, which is just within the uncritical range. It has deteriorated considerably since 2015, due to China more than doubling its exports of LIBs.

This situation will not change in the medium term, even with Europe and the United States developing their manufacturing capacities for battery cells. These are mostly destined for local markets rather than for export. China, South Korea and Japan will still be the largest net exporters of LIBs.

2.5.2 German imports

Table 12 shows Germany's import volumes for 2021 in relation to global imports of the commodity groups considered. No imports have been recorded for lithium oxide and lithium hydroxide since 2007 because of a blocking notice in the databases (personal communication DESTATIS 2017) and the 2007 figures were therefore used for comparison. There are no specific commodity codes for lithium chloride and spodumene concentrates that would permit calculation of the import volumes. Since there is no primary lithium extraction in Germany at present, dependence on imports of this metal and its compounds is still very high.

2.5.2.1 Country concentration and weighted country risk for German imports

Lithium carbonate (HS code 2836.91)

In 2021, Germany imported 6,524 t of lithium carbonate goods with a total value of almost €47m (DESTATIS 2022), accounting for 3.3 % of total global imports (global ranking 2021: 7; 2015: 5).

Germany's imports were mainly from Chile (3,167 t, 48.5 %), Belgium (1,735 t, 26.6 %) and the United States (750 t, 11.5 %). In total, around 87 % of German imports came from three supplier countries, of which only Chile and the United States are primary producers. If Belgian imports are considered as well, it is evident that most of these (>95 %) were also from Chile. But Belgium also has a secondary production sector. The ratio between exports of primary material (from Chile etc.) and lithium from recycled material is not known, but can probably be neglected at present.

Table 12: German imports of lithium compounds in tons for 2021 (data source: IHS Markit 2022, DESTATIS 2022).

HS commodity code[1)]	Imports global [t]	Imports Germany [t]	Share [%]	Global ranking GER	HHI imports GER	GLR imports GER
HS 2836.91	~ 195,398	~ 6,524	~ 3.3	7	3,246	0.95
HS 2825.20	~ 113,209	~ 4,261[2)]	~ 3.6	n/a	5,401	1.47
	~ 24,204[3)]	~ 5,150[3)]	~ 21.3	1		
HS 2827.39.xx	~ 200[4)]	n/a	n/a	n/a	n/a	n/a
HS 2530.90.xx	n/a	n/a	n/a	n/a	n/a	n/a
HS 8507.60	~ 5,608,133,598[5)]	~ 281,999,945[5)]	~ 5.0	5	2,340	0.71

[1)] HS = Harmonised System of the World Customs Organisation (WCO);
[2)] data based on exports to Germany, due to a blocking notice for German imports in place since 2007
[3)] 2007 import volumes
[4)] estimate due to missing HS classification
[5)] units (battery cells)

Market concentration of imports of lithium carbonate was worryingly high in 2021, with an HHI value of 3,246. The weighted country risk (WCR) calculated as 0.95, however, can be considered uncritical. This WCR is principally the result of the import volumes from Chile, Belgium and the United States and the individual country risks of 0.89 (Chile), 1.20 (Belgium) and 0.97 (USA). Of the countries exporting to Germany, only China was assessed as moderately critical in 2021 (–0.25). This did not affect the WCR, however, because of the small volumes supplied by China. There was little change in the HHI compared to 2015, while the WCR deteriorated (see Schmidt 2017).

Overall, Germany's dependence on imports of lithium carbonate based on the HHI and GLR indicators can be considered uncritical, but with a tendency towards the moderately critical.

Lithium oxide and hydroxide (2825.20)

Being subject to a blocking notice, German imports of commodity group 2825.20 (lithium oxide and hydroxide) are not published. We therefore considered exports to Germany reported by other countries instead.

In 2021, around 4,260 t of lithium oxide and hydroxide exports to Germany worth about €20.4m were recorded. German imports calculated on that basis were mainly from the Netherlands (3,023 t, 70.9 % share), the United States (767 t, 18 % share) and Belgium (244 t, 5.7 % share). In total, around 94.7 % of German imports thus identified came from just three supplier countries.

The level of diversification of lithium oxide and hydroxide imports in 2021 was low and in a critical range with an HHI of 5,401. Country concentration was considerably higher than in 2015. At 1.47, the weighted country risk (WCR) is in the uncritical range.

Lithium-ion batteries (8507.60)

In 2021, Germany imported around 282 m units with a total value of almost €8.5bn (IHS 2022), accounting for about 5 % of total global imports (global ranking: 5). Compared to 2015, imports

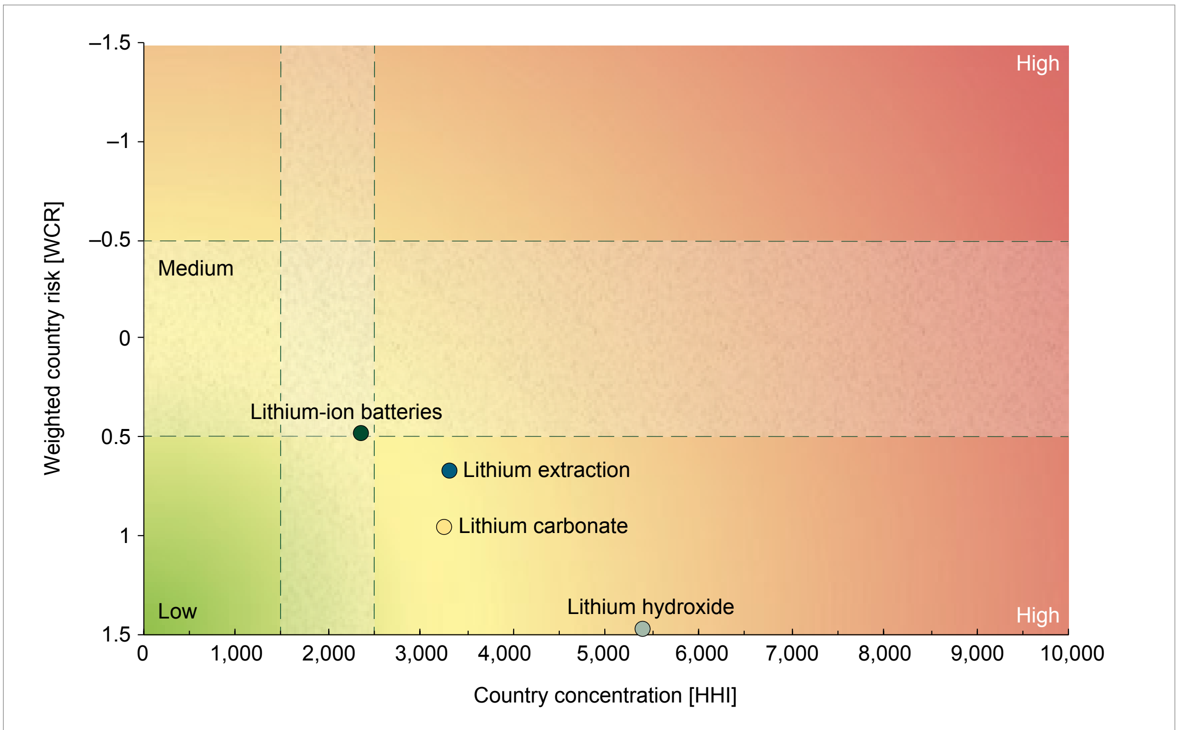

Fig. 18: Weighted country risk and diversification of German imports in relation to lithium mining output (data sources: BGR 2022, IHS Markit 2022).

increased by about 200m units and more than €5bn.

In line with the global value chain, imports were mostly from China (122m units, 43.2 % global share), South Korea (35m units, 12.4 % global share) and Japan (34.6m units, 12.3 % global share). Around 68 % of all German imports came from these three supplier countries, which are also the largest global battery producers.

At 2,340, the HHI for LIB imports to Germany is just within the moderately critical range. The level of diversification fell slightly compared to 2015. The calculated weighted country risk (WCR) of 0.47 is just within the moderately critical range and slightly higher than in 2015. In Europe, and particularly in Germany, a cell manufacturing industry for LIBs may be emerging. This could reduce import dependence for these products, provided the upstream value chains were also locally based.

2.6 Trends in supply and demand

2.6.1 Resources

According to USGS figures (2022), global lithium reserves in 2021 amounted to around 22.4m t Li content. Most of this is concentrated in the currently largest mining countries Chile (9.2m t Li content, 41 %) and Australia (5.7m t Li content, 25.4 %). The category "Other countries" accounts for 2.7m t Li content (12 %; Fig. 19). No data are available on the Bolivian reserves at Salar de Uyiuni.

Global lithium resources (inferred, indicated, measured) amount to around 88.6m t Li content (USGS 2022). With about 21m t Li content (23.7 %), Bolivia ranks first in this category. The three largest producer countries currently account for around 38 % of global resources. Australia as the most important supplier of spodumene concentrates ranks fifth, with around 7.3m t Li content (8.2 %). Chile, the largest producer in South America, is in third place with about 9.8m t Li content (11.1 %). Germany is in ninth place, with around 2.7m t Li content (3 %).

According to S&P Global (2022), global reserves and resources together amount to around 179m t Li_2O across 83 projects in ten countries. That is equivalent to about 83m t Li content. Argentina accounts for the largest share, with about 21m t Li content (25.3 %) across 20 projects. For Germany, two projects with 3.2m t Li content (3.9 %) in total are listed.

Lifespan indicator and extent of exploration

The lifespan indicator (see glossary in the appendix) is calculated from the ratio of global reserves to annual global mining output. It indicates the extent of exploration. Based on current lithium mining output of around 82,117 t of Li content and the reserves according to USGS (2022), the resulting lifespan is about 273 years and thus in the uncritical range. The lifespan indicator is considerably lower than for 2015 (see Schmidt 2017). There are no consistent data for the lithium market on the extent of exploration or the exploration budget.

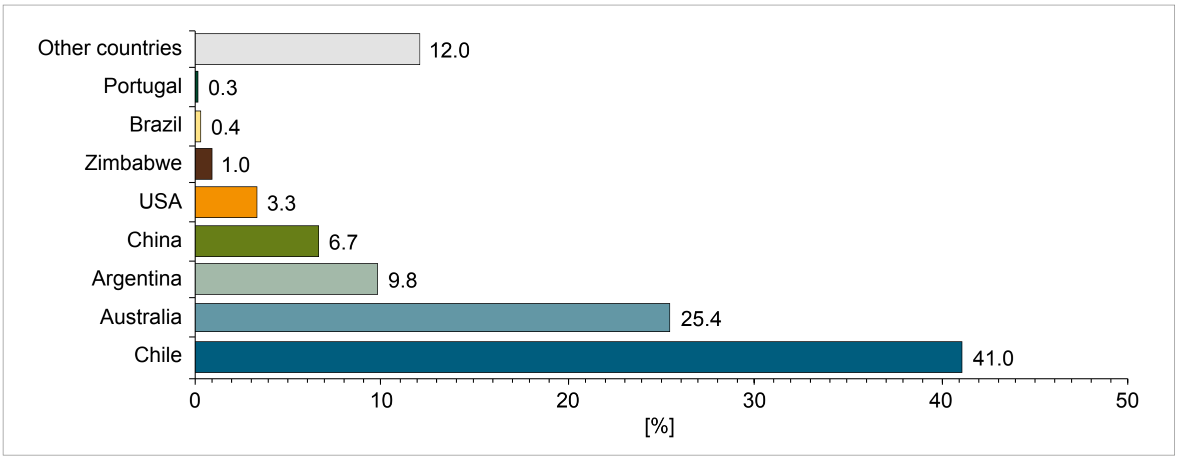

Fig. 19: Percentage distribution of global lithium reserves for 2021 (data source: USGS 2022).

Country concentration and country risk for reserves

About 86 % of known lithium reserves are concentrated in just five countries. At about 2,628, the HHI is just within the critical range (see appendix), while the weighted country risk for reserves is 0.76 and thus well within the uncritical range (see appendix).

2.6.2 Call for Lithium (InvestChile)

Alongside Australia, Chile is currently the largest global lithium producer. By the middle of this decade, however, it could lose its rank to Argentina. One reason is the complex, historically grown structure of the Chilean lithium sector.

Lithium has been classed as a “material of nuclear interest” since 1975 and is managed by CCHEN (Chilean Nuclear Energy Commission). State ownership of lithium was declared in 1979 and all exploration licences are issued by CORFO (Corporación de Fomento de la Producción), a Chilean government body set up in 1939 to boost economic growth. The two largest Chilean producers, SQM and Albemarle, produce lithium at the Salar de Atacama under licence from CORFO.

In 2016 and 2017, the Chilean government took first steps to reform and open up the country’s lithium industry. With its “1st Lithium Call”, Chile was to become a more attractive location for the lithium industry. A major aim of this scheme was to attract companies that produce products of higher added value. Details of the framework parameters of the original development programme can be found in Schmidt (2017).

In May 2017, the scheme was presented to German companies in Frankfurt, Germany, by CORFO, InvestChile and Albemarle in the presence of the Chilean ambassador. InvestChile is a public agency that promotes foreign investment in Chile.

CORFO had tied this first scheme to the direct and exclusive purchase of precursors from Albemarle, while SQM was not included. At the programme’s core was exclusive access to lithium carbonate, lithium hydroxide and lithium chloride at preferential prices. Its overall objective was to maintain or even expand Chile’s market share. Pricing was to be based on Albemarle’s lowest average export prices (FOB Chile) in the previous six months (Corfo 2017a). Buyers were to be guaranteed a secure supply of precursors until 2044. The production of lithium hydroxide and lithium chloride or high-purity lithium carbonate from the supplied precursors was not permitted under the scheme. Products of higher added value included, for instance, cathodes, battery components and other lithium compounds.

Six existing industrial areas were selected as business locations where value-adding companies would be able to purchase land at special conditions to set up operations. Among them are Alto Hospicio (Iquique), La Negra Sur, La Negra Norte, Mejillones, Salar des Carmen and Diego de Almagro (CORFO 2017b). The scheme failed to attract any investment from the industry and Chile’s market share thus fell to 26 % in 2020. At the time, CORFO had estimated that Chile would have a market share of about 25 % in 2025 if the scheme were to fail to meet its objectives.

In the first quarter of 2019, a second programme followed (National and International Call for Specialized Producers of Lithium-Based Products To Invest in Production Capacity in Chile). It was similar in structure to the first, the main difference being that SQM and not Albemarle was named as the supplier.

The call was for national or international companies with proven experience and the technical and financial capabilities to establish a value chain in Chile. Applications from consortia, joint ventures and other types of partnerships were explicitly requested. Pricing was again to be based on SQM’s lowest average export prices (FOB Chile) in the previous six months (Corfo 2019). This scheme failed, too, as it was unable to attract any major investment or industrial development.

A third invitation to tender was therefore launched. It is domestic and international and aims to substantially boost lithium production in Chile to meet growing global demand, while also counteracting the decline in Chile’s market share resulting from a lack of new projects (GOB 2022). Unlike the first two calls, this third programme is aimed at primary production rather than battery industry products of higher added value.

Under the call, bids were invited for two production quotas of 80,000 t Li content (approx. 426,000 t LCE) each. The period during which these quantities can be produced is set at more than 20 years. The quotas are, however, not allocated to specific deposits. Because of the legal principles for the awarding of licences in Chile, the Salar de Atacama (owned by CORFO) and the Salar de Maricunga (exploration licences owned by CODELCO), for instance, are not readily eligible.

The successful bidders for the two licences (Special de Operación de Litioà CEOLs) were BYD Chile SpA and Servicios y Operaciones Mineras del Norte S.A. (Gruppo Erazuris), each paying around U$S61m. SQM and Albemarle participated but their bids were lower and therefore not successful.

Because of doubts regarding the legal basis for the procedure and its execution, the tender details were submitted to the Supreme Court for review. The tender had been carried out under the government of President Sebastián Piñera two months before his term ended, which is why there are doubts about its legality. Appeals against the licences were launched by the indigenous communities of Camar.

One major point of criticism is the fact that exploration licences were awarded that were not explicitly linked or allocated to a specific deposit. The indigenous communities could therefore not be consulted and included. On these grounds, the Supreme Court upheld two appeals by indigenous communities on 2 June 2022 and voided the disputed lithium tender (Compañía Chilena de Comunicaciones S.A. 2022). It is unclear whether or not there will be a new tender.

CORFO started a new tender procedure in August 2022. This call (specialised lithium producers in Chile) is for a term of one year (08/2023) or until the quota is exhausted. Its aim is to attract companies to Chile who will invest in and develop value-added products such as precursors and/or cathode material, battery cathodes, other lithium battery components, lithium metal etc. They will receive preferential supplies of lithium carbonate and lithium hydroxide at preferential prices from SQM. Monthly volumes are around 1,875 t of lithium carbonate and about 350 t of lithium hydroxide (Corfo 2022). All terms and conditions can be accessed at https://www.corfo.cl/sites/cpp/landing_litio.

In addition, the new Chilean government under President Boric has announced a regulatory overhaul of the entire lithium industry. Plans range from a nationalisation of the whole sector to a state-owned lithium company. There is no consensus at present about the orientation of the industry over the next few years. The upcoming contract negotiations between CORFO and SQM could play a major role in this respect, since the company's licence at the Salar de Atacama is theoretically due to expire in 2030. Albemare's licence will run until the end of 2043.

There are also aspects of sustainable exploration in Chile and political restructuring. All these factors could have an impact on the future development of output volumes controlled by production quotas put out to tender.

2.6.3 Future global supply

Future supply is estimated based on primary extraction and production and the secondary industry (battery recycling). As part of this study, we prepared supply scenarios for lithium until **2030**.

2.6.3.1 Primary supply

Primary supply is based on current mining output, planned capacity expansions and mining projects with their annual productive capacities and the planned start of production. Capacity figures for new mining projects and capacity expansions are target figures from the mining and exploration companies. Only exploration projects with the status PFS/DFS (completed/ongoing) are considered here.

Capacity expansions/restarts

Data about planned capacity expansions and restarts, in some cases a combination of both, are currently available from nine companies (Table 13). All these companies and projects are of major importance for the supply scenarios until 2030. They are described in detail below.

Talison Lithium: The Australian company Talison Lithium is planning to expand the capacity of its Greenbushes mine from currently around 200,300 t LCE (approx. 37,600 t Li content) to around 396,200 t LCE (approx. 74,500 t Li content; IGO 2020). The expansion by 36,900 t Li content will be implemented in stages depending on the market environment, between 2022 or 2024 and 2027. No fixed date has been set for the last stage (CGP4).

Albemarle, as a joint venture partner at Greenbushes, is also benefiting from this expansion project in Australia. The additional concentrate from Greenbushes will be processed in the lithium carbonate and lithium hydroxide production plant under construction at Kemerton (Australia). This plant was originally planned with a capacity of 100,000 t LCE, but was downsized by 50 % because of 2020 price trends. Kermerton is operated in a (60/40) joint venture with Mineral Resources (Mineral Resources 2022).

Mineral Resources: Founded in 2006, Mineral Resources originally provided services to the mining sector. Min. Res. now operates two lithium mines in Australia as a joint venture partner: Mt. Marion with Ganfeng Lithium (50/50), and the Wodgina mine with Albemarle (50/50). Original partners Neometals and Reed Industrial Minerals sold their shares.

For **Mt. Marion**, Mineral Resources signed a “toll treating agreement” with Ganfeng Lithium, under which it buys all of the concentrates produced (Mineral Resources 2022). Based on Mt. Marion’s productive capacity for 2020, a 10–15 % increase in output (1,250–1,880 t Li content) is planned for the next few years.

The **Wodgina** mine is due to restart production in the fourth quarter of 2022, with an expansion planned immediately afterwards. The planned annual capacity of Train 1 is about 37,000 t LCE (6,970 t Li content), to be available in 2030. In the event of a positive development of the overall market, a further expansion by Trains 2 and/or 3 is possible, but there is no schedule for this yet. It would roughly correspond to 74,200 t LCE (13,900 t Li content) more capacity. In total, the Wodgina mine could supply an additional 6,970 t–20,870 t Li content.

All potential output of concentrates from Wodgina will be listed under Mineral Resources as the operator, thus avoiding double counting. All concentrate output from Wodgina is processed by Albemarle in China. These processing capacities are financed as a (50/50) joint venture between Albemarle and Mineral Resources, with Albemarle assuming responsibility for operation and sales (Mineral Resources 2022).

Pilbara Minerals: With rapid expansion, Pilbara Minerals has quickly become one of the largest producers worldwide (Table 13). Having acquired the licences for Pilgangoora only in 2014, it has since developed the project. In 2020, Pilbara Minerals took over the neighbouring company Altura Mining (previously also trading as Morella). Its productive capacity, currently around 45,000 t LCE (8,400 t Li content), is to be increased significantly in the next few years to about 51,700 t LCE (9,700 t Li content), through process optimisation of the original plant (Pilgan).

A further step the company is planning is to restart production at the former Altura plant (now Ngungaja) and expand it to a total capacity of 27,200 t LCE (5,110 t Li content). According to Pilbara Minerals, this ramp-up is in progress, with the first concentrate output expected for mid- to late 2022. Depending on the market situation, the Pilgan plant could be expanded, but there is no schedule for this yet. These potential expansion projects (P680, P1,000) could provide roughly an extra 57,100 t LCE (10,700 t Li content; Pilbara Minerals 05/2022). In total, an additional 6,390 t–17,400 t Li content could become available on the market in 2030, ranking the company among the top 3 lithium producers that year.

Livent: In July 2018, FMC Corp. demerged its lithium business, rebranding it Livent Corp. (PR Newswire 2019). Its current productive capacity of around 20,000 t LCE (3,760 t Li content) is to be doubled by the end of 2023 (stages A, B), with another expansion by 30,000 t LCE (5,636 t Li content) planned to come by late 2025. A further option is to expand by an additional 30,000 t LCE (5,636 t Li content) by 2028/2029 (**Livent** 2022). This would make up to an additional 80,000 t LCE (15,030 t Li content) available by 2030.

Together with Investissement Québec, Livent has also taken over the lithium business of the former **Nemaska Lithium** as a (50/50) joint venture (S&P Global 2022). Livent will also be operating the plant in Canada. There are plans to restart it, with output from about 2026 of up to 34,000 t lithium hydroxide, which corresponds to the plant's capacity.

SQM: The Chilean company SQM operates its plants in the immediate vicinity of Albemarle at the Salar de Atacama, where it is licensed by CORFO to extract lithium brine until 2030. Expansion projects at the La Carmen plant (Antofagasta) will involve increasing output and optimising processes in the salar.

According to company figures, the capacity in Chile will rise from 120,000 t LCE p. a. (22,500 t Li content) in 2020 by 60,000 t LCE (11,200 t Li content) to 180,000 t LCE (33,700 t Li content) in 2022 (SQM 2022). Political developments in Chile and negotiations with CORFO will determine to a large extent whether additional expansion projects are possible. The lithium hydroxide capacity is due to grow to 30,000 t (4,950 t Li content) in 2022; this figure is included in the above overall capacity data (personal communication SQM 2022).

Albemarle: Albemarle can produce up to 80,000 t LCE (15,040 t Li content) p. a. from the deposits in Chile (Salar de Atacama) until 2044. This quota is based on a 2017 Amended Lithium Production Rights Agreement with CORFO (Albemarle 2017). All brine concentrates will be processed at La Negra and all additional future supply therefore depends on a capacity expansion of this plant. The planned expansion projects La Negra III and IV are designed to provide an additional capacity of 40,000 t LCE p. a. (7,500 t Li content) from 2021/2022. Moreover, process optimisation of the existing plants will increase the yields while also reducing water consumption. This expansion by about 7,500 t Li content is therefore a major factor in the supply up to 2030.

Allkem: In 2021, Allkem Ltd was formed by spinning off the lithium business of Orocobre (Allkem 02/2022). This was merged with Galaxy Resources in August 2021 (Allkem 08/2022). According to company figures, its capacity in Argentina (Salar de Olaroz) is due to rise by 25,000 t LCE (4,700 t Li content) to 42,500 t LCE (7,990 t Li content) from late 2022. Before this planned expansion, however, Phase 1 will have to achieve full capacity (17,500 t LCE, 3,290 t Li content). Capacity expansion projects at Mt. Cattlin are currently under discussion.

Bald Hill: The Bald Hill mine was commissioned by Tawana Resources in 2018. Because of plummeting prices (Section 2.1.1), the company went into administration in mid-2019. Since then, the mine has been under care and maintenance. Due to legal problems following insolvency, it has not been possible to restart production. A full subsidiary of Tawana Resources, Alita Resources, is planning to restart the company shortly (Australian Financial Review 2022). Based on 2018 productive capacities and 2019 output figures, Bald Hill could supply an additional 3,200 – 4,300 t Li content to the market in 2030.

AMG: In Brazil, AMG operate the Mibra mine (AMG Mineracao), which they acquired in 1978. Its annual capacity of 90,000 t of concentrate is currently being expanded by a planned 40,000 t of concentrate (approx. 1,100 t Li content; AMG 01/2022). Most of the concentrate will temporarily be processed to lithium salts in China. Ultimately, processing is due to take place at Bitterfeld (Bitterfeld-Wolfen chemical park), where AMG Lithium are currently building a processing plant.

Mines under construction

Information about mines under construction is currently available for nine companies (Table 13), six of them in Argentina.

Xuxa: In Brazil, Sigma Lithium is developing the Xuxa project. Construction started in late 2021. When the first stage is complete, it is expected to produce up to 33,000 t LCE (6,200 t Li content) from late 2022. A second stage is planned. This is to increase capacity by another 33,000 t LCE (6,200 t Li content; Sigma Lithium Corp. 2022). According to Sigma Lithium, binding offtake agreements with LG Chem already exist. A third stage is under discussion.

Cauchari Olaroz: Lithium Americas is developing the Cauchari-Olaroz project in Argentina in a (51/49) joint venture with Ganfeng. Their joint project share is 91.3 %. The other shares are owned by Jujuy Energia y Mineria. Two stages of development are planned. In the first, the project is expected to produce up to 40,000 t LCE (7,500 t Li content) in late 2022 following ramp-up. The second stage from mid-2025 will make available up to 20,000 t LCE (3,800 t Li content; Lithium Americas Ltd. 2022).

Table 13: Overview of the currently most important lithium projects with the status capacity expansion/restart, and mines under construction (company figures, see references).

Project name	Country	Company	Status	Planned additional annual capacity [t Li cont.] (year)	Planned start of production	Reserves/ resources [m t Li cont.]
Greenbushes[1)]	Australia	Talison Lithium	Expansion	36,900	from 2022[2)]	1.4/1.8
Wodgina[3)]	Australia	Mineral Resources	Restart + expansion	6,970–20,870[4)]	Q4/2022	0.8/0.6
Pilagangoora/ Ngungaja[5)]	Australia	Pilbara Minerals	Restart + ex-pansion	6,390–17,400[6)]	from Q4/2022	0.9/0.7
Salar del Hombre Muerto	Argentina	Livent	Expansion	up to 15,030[7)]	from Q4/2022	n/a/0.8
Salar de Atacama	Chile	SQM	Expansion	11,200	from 2022	n/a/n/a
Salar de Atacama	Chile	Albemarle	Expansion	7,500	from 2022	n/a/n/a
Whabouchi[8)]	Canada	Livent	Restart	up to 5,620	from 2026	0.2/0.36
Salar de Olaroz	Argentina	Allkem	Expansion	4,700	Q4/2022	n/a/3
Bald Hill	Australia	Alita Resources	Restart	3,200–4,300[9)]	2022/2023	0.1/0.06
Mt. Marion[10)]	Australia	Mineral Resources	Expansion	1,250–1,880[11)]	n/a	n/a/0.5
Mibra	Brazil	AMG Mining	Expansion	1,100	from Q4/2022	n/a/0.07
Xuxa	Brazil	Sigma Lithium	under construction	6,200–12,400[12)]	from 2022	0.2/0.09
Cauchari Olaroz[13)]	Argentina	Lithium Americas	Im under construction	7,500–11,300[14)]	Q4/2022	3.9/0.7
Mt. Holland	Australia	Covalent Lithium[15)]	under construction	8,300	Q4/2024	0.6/0.6
Finnis	Australia	Core Lithium	under construction	5,600	Q4/2022	0.05/0.09
Centenario Ratones	Argentina	Eramet	under construction	4,500	2024	1.8/0.02
Sal de Oro	Argentina	Posco Argentina	under construction	4,130	2024	n/a/n/a
Sal de Vida	Argentina	Allkem	under construction	2,820	H2/2023	0.3/1
Salar de Rincon	Argentina	Argosy Minerals	under construction	380–2,250[16)]	H2/2022	n/a/n/a
Mariana	Argentina	Ganfeng	under construction	1,900	Q4/2024	0/1

[1)] JV between Tianqi and Albemarle
[2)] no start date for stage CGP4
[3)] JV between Mineral Resources and Albemarle
[4)] restart Train 1 (6,970 t) and expansion Train 2/3, no start date
[5)] expansion of Pilgangoora and restart Ngungaja (formerly Altura Mining)
[6)] incl. stages P680 and P1.000 (no start date)
[7)] expansion in stages
[8)] JV between Livent and Investissement Québec
[9)] based on figures from CANNACORD (2017)
[10)] JV between Mineral Resources and Ganfeng Lithium
[11)] output increase of 10–15 %;
[12)] expansion in stages (2022–2025)
[13)] JV between Lithium Americas and Ganfeng
[14)] expansion in stages (2022/2025)
[15)] JV between SQM and Westfarmers
[16)] expansion in stages

Mt. Holland: This project is located in Australia, in the state of Western Australia. It is a (50/50) joint venture between SQM and Westfarmers, developed by Covalent Lithium (SQM 02/2021). Following completion and successful ramp-up, it is expected to produce up to 44,000 t LCE (8,300 t Li content) from late 2024.

Finnis: This Core Lithium Ltd. project is located southwest of Darwin in the north of Australia. Construction started in mid-2021 and first exports of spodumene concentrate are expected to leave the port of Darwin in late 2024 (Core Lithium Ltd. 2022). There are offtake agreements for 150,000 t of concentrate with Ganfeng Lithium and Yahua. The planned output is around 30,000 t LCE (5,600 t Li content).

Centenario Ratones: This project by Eramet and Tsinghan Steel is under development in Salta province, Argentina. Construction started in 2021. Following completion in 2024, the project is expected to produce up to 24,000 t LCE p.a. (4,500 t Li content; Eramet 2022).

Sal de Oro: This project by Posco Argentina is under development at the Salar de Hombres Muertos in Argentina. A pilot plant has been running successfully for about a year. From 2024, the project is expected to yield up to around 25,000 t lithium hydroxide p.a. (22,000 t LCE or 4,130 t Li content; POSCO 2022).

Sal de Vida: Located in Catamarca province, Argentina, this project is wholly owned by Allkem (formerly Orocobre). The production of lithium carbonate is expected to start in the second half of 2023, with a capacity of up to about 15,000 t LCE p. a. (2,820 t Li content; stage 1).

Salar de Rincon: This project in Salta province, Argentina, is being developed by Argosy Minerals. A first stage (pilot) with a productive capacity of just 2,000 t LCE (380 t Li content) is currently under construction (Argosy Minerals 2022). It is due to be commissioned in mid-2022, producing lithium carbonate. Another stage has been approved and is under construction. This is expected to provide an additional 10,000 t LCE (1,900 t Li content).

Mariana: Construction of this project by Ganfeng Lithium, Lithium Minera Argentina SA. started in May 2022 (Glacier Media 2022). It is located at the Salar de Llullaillaco in Salta province, Argentina. From 2024, 20,000 t LiCl yielding 10,000 t LCE p. a. (1,900 t Li content) will be extracted/produced there.

Table 14: Overview of the currently most important lithium projects with the status PFS/DFS (company figures, see references)

Project name	Country	Company	Status	Planned additional annual capacity [t Li cont.] (year)	Planned start of production	Reserves/ resources [m t Li cont.]
Kathleen Valley	Australia	Liontown	DFS	14,000 – 20,700	2024 – 2033	0.43/1
Manono	DR Congo	AVZ Minerals	DFS	19,500	2024	1/2.1
Goulamine	Mali	Firefinch	DFS	14,100	n/a	0.36/0.36
Thacker Pass	USA	Lithium Americas	FS (in progress)	11,000	n/a	0.59/3.4
Jadar	Serbia	RioTinto	DFS	9,600	n/a	n/a /1.2
James Bay	Canada	Allkem	DFS	8,900	2024	0.22/0.26
Oberrhein-graben	Germany	Vulcan Energy	PFS, DFS (in progress)	2,500 – 6,600	2024	2.8/2.8
Sonora	Mexico	Bacanora Minerals	FS	3,290 – 6,580	2023	0.85/0.81
Rose Tantalum	Canada	Critical Elements	FS	5,720	2023	0.1/0.15
Carolina	USA	Piedmont	FS	5,000	n/a	0.09/0.22

Project name	Country	Company	Status	Planned additional annual capacity [t Li cont.] (year)	Planned start of production	Reserves/ resources [m t Li cont.]
Mina de Barroso	Portugal	Savannah Resources	DFS (in progress)	4,900	2023	n/a /0.13
Cinovec	Czech Republic	European Metals	PFS, DFS (in progress)	4,900	n/a	n/a /1.4
Kachi	Argentina	Lake Resources	DFS	4,700	2024	n/a /0.83
Pastos Grandes	Argentina	Lithium Americas	DFS	4,500	n/a	0.18/0.15
Smackover	USA	Standard Lithium	DFS (in progress)	4,000	n/a	n/a /0.6
3Q	Argentina	NeoLithium	PFS	3,760	n/a	n/a /1.4
Ryolite Ridge	USA	Ioneer	DFS	3,600	2025	0.11/0.23
Hells Kitchen	USA	CTR	PFS	3,300	2024	n/a / n/a
St. Jose	Spain	Infinity Lithium	PFS, DFS (in progress)	3,200	n/a	n/a /0.54
Maricunga	Chile	Lithium Power	DFS	2,860	n/a	0.14/0.4
Georgia Lake	Canada	Rocktech Lithium	PFS/FS	2,590	2024	n/a /0.07
Keliber Oy	Finland	Keliber	DFS	2,070	2024	0.05/0.04
Karibib	Namibia	Lepidico	DFS	1,300	2024	0.015/0.01
Arcadia	Zimbabwe	Prospect Resources	DFS	n/a	n/a	0.24/0.12
NAL/Authier	Canada	Sayona	DFS	n/a	n/a	0.15/0.37
Wolfsberg	Austria	European Lithium	DFS (in progress)	n/a	2024	n/a /0.13
Zinnwald	Germany	Zinnwald Lithium	DFS	n/a	n/a	n/a /0.13

Table 15: Overview of potential additional annual productive capacity from expansions, projects under construction/development, restarts, selected projects and lithium recycling.

Status	Number	Planned capacity by 2030 [t Li cont./p.a.]	Expected capacity 2030 (supply scenario 1) [t Li cont./p.a.]	Expected capacity 2030 (supply scenario 2) [t Li cont./p.a.]
Expansion projects[1)]	10	90,475	71,689	90,475
Under construction/ development	9	41,894	41,894	41,894
Restarts[2)]	4	9,769	0	9,769
Projects (PFS & DFS)[3)]	27	151,869[3)]	13,150[3,4)]	106,308[4)]
Recycled supply	–	36,160[5)]	9,040[6)]	27,120[7)]
Expected capacity[8)]			**135,772**	**275,563**

[1)] Nine companies (10 projects), expansion plans without specific schedules are considered with reduced capacity
[2)] two of the four projects are also expansion projects
[3)] some projects with reduced total capacity
[4)] assumed for China (not project-specific)
[5)] based on a 100 % recycling rate and a 2,000 GWh demand scenario
[6)] recycling rate of 25 %
[7)] recycling rate of 75 %
[8)] deviations possible due to rounding

Mining projects

This table gives an overview of the most important projects with the status PFS/DFS (completed/ongoing) taken into account in supply scenario 2. They were selected based on the level of development, reserves/resources, and joint ventures and/or offtake agreements (binding/non-binding) announced.

2.6.3.2 Secondary supply

Since the demand forecast for the next few years will significantly exceed primary supply, the secondary sector will play an increasingly important role in overall supply. To date, secondary supply, i. e. from recycled material, was of relatively little importance in the global context.

Regulatory activities and laws will drive the trend towards use of secondary resources. A clear trend towards the circular economy and sustainability is emerging.

Only the recycling of e-mobility LIBs is considered here for the supply of secondary lithium. None of the other areas of application (Section 1.4) play a role. In order to quantify the recycling share, we made the following assumptions regarding return rates:

- 50 % return rate for LIBs after eight years' use;
- 60 % return rate for LIBs after ten years' use;
- 90 % return rate for LIBs after twelve years' use;
- loss of the remaining 10 % through production waste and export losses.

Continued use as a second-life battery was not taken into account either. This would make the return period for LIBs significantly longer. The supply from recycling is based on the forecast e-mobility demand figures until 2030. It is also assumed that the recovered lithium can be reused directly in LIBs.

Depending on the supply scenario, potential recycling rates of 25 % and 75 % were assumed, as it is still difficult to recover lithium in a metallurgical process and economic recovery is therefore not yet possible. DERA's demand scenarios for e-mobility (Section 2.6.5.1, Table 19) form the basis for calculating the supply (Table 16) from recycling.

An assessment of raw material quantities has to take into account that no single LIB type has so far emerged as dominant and it is not yet clear which type will prevail in future. Estimates of the recycling share and the economic operation of current recycling plants and investments in new plants are therefore relatively uncertain. Potential recycling processes will either have to be designed to handle different cell types, or individual companies will have a selective focus. Processes will also need to be scalable, to permit economic operation.

Potential supply quantities from LIB recycling for 2030 are shown below for different market growth scenarios and recycling rates (Table 16). Depending on the scenario and rate, roughly up to 56,000 t Li content (298,090 t LCE) from recycling are available in 2030.

The conservative supply scenario (Section 2.6.6) is based on DERA recycling scenario 2 with a

Table 16: Overview of potential additional lithium supply from LIB recycling.

DERA-recycling scenario	Recycling supply 2030[4] [t Li cont.] 100 % rate	Recycling supply 2030[4] [t Li cont.] 75 % rate	Recycling supply 2030[4] [t Li cont.] 50 % rate	Recycling supply 2030[4] [t Li cont.] 25 % rate
Scenario 1[1]	49,720	37,290	24,860	12,430
Scenario 2[2]	36,160	**27,120**	18,080	**9,040**
Scenario 3[3]	55,640	41,730	27,820	13,910

[1] E-mobility demand = 3,140.5 GWh (SSP1)
[2] E-mobility demand = 2,004.2 GWh (SSP2)
[3] E-mobility demand = 4,500 GWh (DERA)
[4] supply refers only to e-mobility LIBs; 50 % return rate after eight years; 60 % return rate after ten years; 90 % return rate after twelve years; 10 % losses.

recycling rate of 25 % **(9,040 t Li content)**. The optimistic supply scenario (Section 2.6.6) is also based on DERA recycling scenario 2, but with a recycling rate of 75 % **(27,120 t Li content)**.

According to Benchmark Minerals, the 2030 recycling supply could add roughly 40,000 t Li content (210,000 t LCE) to the supply from mining (personal communication S. Moores, CEO Benchmark Minerals).

2.6.4 Focus on Europe (supply)

Over the past few years, Europe and especially Germany has become an e-mobility hotspot. This applies to markets, i.e. acceptance by end consumers, as well as to the car industry and the battery manufacturing upstream value chain. Only a few years ago, such a development could not have been expected at this speed nor in this form. Crucial factors have been subsidies for electric cars, growing customer acceptance, an expansion of the charging infrastructure, changes in global supply chains, and EU-wide statutory bans on ICEs from 2035.

Although China dominated both manufacturing and sales of battery-powered vehicles for many years, Europe is now playing an increasingly important role. In addition to the established car manufacturers with their announcements, Europe has seen companies locating and expanding capacity for the production of battery chemicals and cell components.

Against this background, we have discussed a separate supply scenario for the **2030** time frame. The focus is on Europe's pure self-sufficiency in lithium. This scenario aims to highlight potentials in Europe and identify possible related import dependencies.

It does not take into account the fact that some cell manufacturing capacities belong to Asian companies with access to lithium outside Europe.

Primary supply Europe

At present, very little lithium is produced in Europe (Table 7), with a total share in 2020 of below 0.4 %. Europe is therefore currently almost totally dependent on imports. Moreover, it has not yet established a significant processing sector either.

Based on the growth scenarios for the production of lithium-ion batteries, import dependence will increase even further. The supply scenario discussed here is based on data for European projects (PFS/DFS completed) from global supply scenario 2.

As they are at an early stage of development, the two potential projects Valjevo (EuroLithium Borates+, Serbia) and Lopare (Arcore Lithium Mining, Bosnia) have not been included in this scenario. Both are combined boron and lithium projects. Due to the market situation regarding boron, these projects must be developed with due care. Arcore are planning to produce up to 25,000 t LCE (4,700 t Li content) from about 2026 (personal communication). No data are available on resources. EuroLithium have not published any potential output figures or time frames, but have said that resources amount to around 9.6m t LCE (1.8m t Li content).

Ideally, European projects would thus be able to provide up to 26,489 t Li content (141,000 t LCE) from mining in 2030. Of this quantity, 70 % are taken into account, as in supply scenario 2 (global).

Secondary supply

To calculate the secondary lithium supply in Europe, the same parameters were used as for the global recycling supply. Potential supply is based on the scenarios for demand until 2030 in Table 17. Within the EU, the share of lithium from recycling in LIBs is to increase to 4 % in January 2030, with a recycling rate of 70 %, and further from 4 % to 10 % in 2035 (European Commission 2020).

Depending on the demand scenario and recycling rate, roughly up to 26,800 t Li content (142,660 t LCE) are available in 2030. The DERA scenario with a cell manufacturing capacity of 1,000 GWh for Europe, 75 % capacity use and a recycling rate of 75 % is considered as optimistic (7,710 t Li content). The same scenario but with a recycling rate of 25 % is the conservative scenario (2,570 t Li content).

Table 17: Overview of potential additional lithium supply from LIB recycling in Europe (DERA 2022).

Demand in 2030 [GWh]	Recycling supply 2030[1] [t Li cont.] 100 % rate	Recycling supply 2030[1] [t Li cont.] 75 % rate	Recycling supply 2030[1] [t Li cont.] 50 % rate	Recycling supply 2030[1] [t Li cont.] 25 % rate
1,310	26,800	20,100	13,400	6,700
1,000	17,160	12,870	8,580	4,290
1,000[2]	10,280	**7,710**	5,140	**2,570**

[1] Supply refers only to LIBs from e-mobility; 50 % return rate after eight years; 60 % return rate after ten years; 90 % return rate after twelve years; 10 % losses
[2] 1,000 GWh reduced to 75 % capacity use (base case).

2.6.5 Future global demand

Based on figures from CRU (2022), historical data for demand are available from 2015 onwards. According to data from Roskill (2016), the compound annual growth rate (CAGR) was only 7 % in the period 2000–2015 (Schmidt 2017), rising to an average of 16.9 % in the period 2015–2020. Between 2020 and 2021, demand rose by 33.4 %, reflecting the highly dynamic nature of the market. Annual growth in demand thus doubled from the average of 2015–2020 within one year.

Demand forecasts beyond 2030 are not very helpful at present, because of the dynamic nature of the lithium market noted above, the global economic situation and potential technological advances. Fig. 20 shows a comparison of global demand scenarios for 2030 based on selected sources including DERA scenarios 1–3.

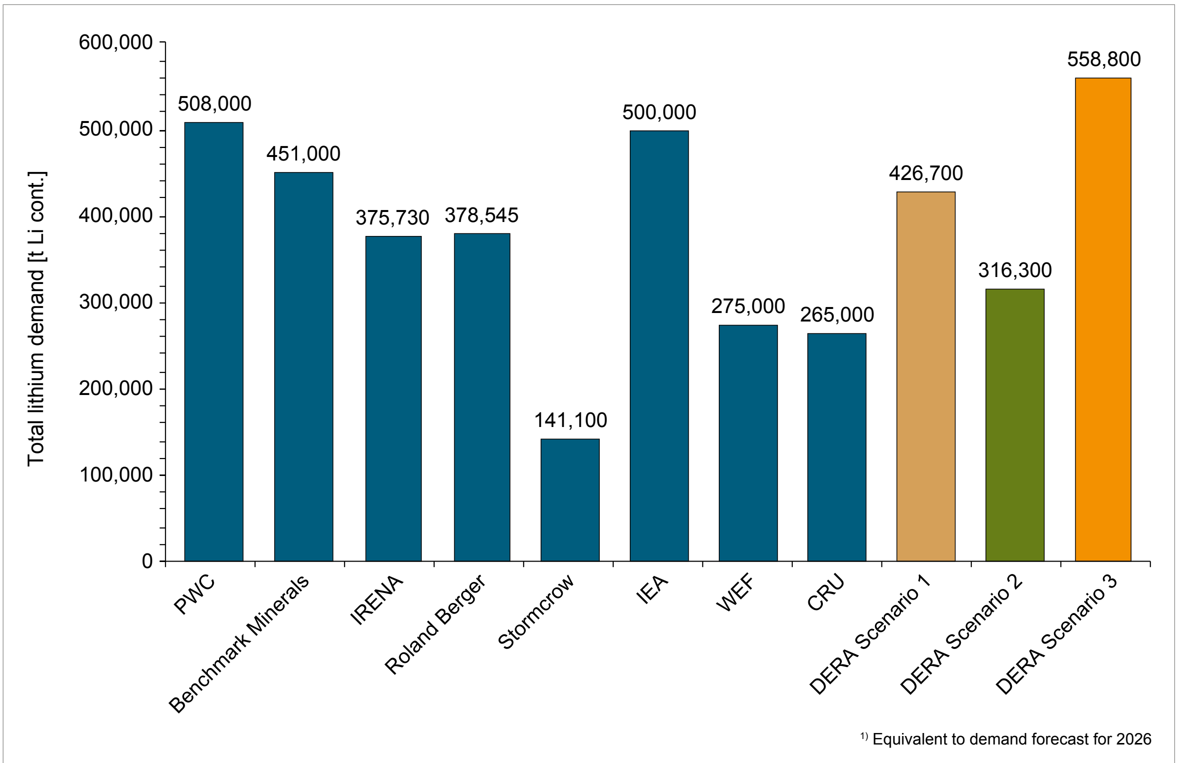

Fig. 20: Total demand forecasts for 2030 and DERA scenarios (data sources: PWC 2022, Benchmark Minerals 05/2022, IRENA 2022, Roland Berger 2019, Stormcrow 2019, IEA 2022, WEF 2019, CRU 2022, DERA 2022).

Table 18: Total demand scenarios for the period 2020–2030 (data source: DERA 2022).

DERA demand scenario	CAGR 2020–2030 (%)	Demand 2030 (t Li content)
Scenario 1[1)]	19.1	426,700
Scenario 2[2)]	15.6	316,300
Scenario 3[3)]	22.4	558,800

[1)] E-mobility demand = 3,140.5 GWh (SSP1)
[2)] E-mobility demand = 2,004.2 GWh (SSP2)
[3)] E-mobility demand = 4,500 GWh (DERA)

The three global DERA demand scenarios are given in Table 18. They are based on demand data and extrapolated demand forecasts from CRU (2022). Data from the DERA study "Raw materials for emerging technologies 2021" (scenarios 1 and 2) in modified form and internal DERA assumptions (scenario 3) were used for the specific application "rechargeable batteries for e-mobility".

2.6.5.1 Future demand in major areas of application

In 2020, the largest markets for lithium by area of application were **rechargeable batteries** (67.1 %) and **ceramics/glass-ceramics/glass** (16.1 %; CRU 2022). The **other areas of application** including lubricants, metal powder, polymers etc. accounted for about 16.7 % of total demand (Section 1.4).

Based on the demand trends forecast by DERA, the following percentage shares result for the individual areas for 2030 (scenario 2, Table 18): **rechargeable batteries** around 88.8 %, 281,022 t Li content; **ceramics/glass-ceramics/glass** around 5.6 %, 17,603 t Li content; **other applications** just under 5.6 %, 17,657 t Li content (Fig. 21).

With faster growth in e-mobility, however, (scenario 3, Table 18), the share of rechargeable batteries in total demand could rise to almost 94 %.

Rechargeable batteries will be the area of application with by far the largest impact on the future total demand for lithium. It is therefore analysed in more detail below.

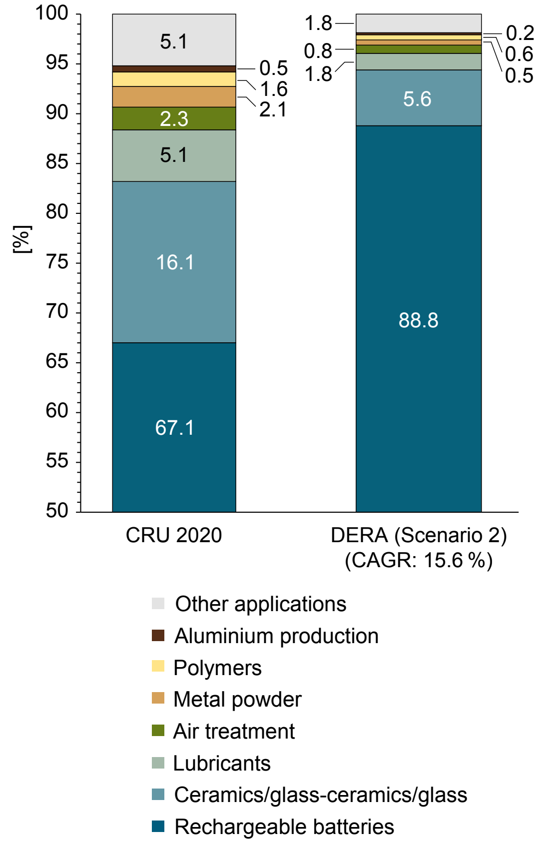

Fig. 21: Demand in 2020 compared to forecast for 2030 (scenario 2, SSP2; data source: CRU 2022).

Rechargeable batteries

The large increase in lithium demand in this sector results from the segments e-mobility, renewable energy storage (ESS), 3C applications (smartphones, laptops, tablets), tools and e-bikes and trikes. Of these, e-mobility is by far the largest and most important driver of demand in terms of quantities.

Forecasts for the segments e-mobility and ESS are very difficult because of the many parameters involved (battery cost, market penetration, ban of ICEs, different markets, legal requirements and regulations, legislative support for e-mobility, technology leaps, competing technologies etc.). Forecasts for the whole area of rechargeable batteries therefore vary widely. Alongside its use as a cathode material, lithium is currently also used in the liquid electrolyte of the cells.

E-mobility

Future demand in this market segment is based on the lithium demand per kWh for the battery technologies assumed to be available up to 2030 (Fig. 22) and for the productive capacities in cell manufacturing assumed for that timeframe.

Data on global productive capacities vary considerably between sources. According to IEA (2021), capacities amounted to around 300 GWh in 2020, with about 160 GWh output. However, for the following year, 2021, Benchmark Minerals (03/2022) already cites a global productive capacity of 1,025 GWh.

For the timeframe 2022 to 2030, assumptions vary even more, because of the highly dynamic market. According to CRU (2022), manufacturing demand in 2026 will be around 1,370 GWh. Total productive capacities in 2030 are estimated to be up to 3,200 GWh, up to 600 GWh of this in Europe (IEA 2021, Thielmann et al. 2021). According to McKinsey (2022), however, 2030 demand could in fact rise to 4,000–4,500 GWh. RhoMotion, a consulting firm specialising in the battery industry, on the other hand, forecasts cell manufacturing capacities of around 2,340 GWh for 2030 (Rho-Motion 2022). For 2031, Benchmark Minerals (02/2022) even assumes global cell manufacturing capacities of around 5,454 GWh, 16 % of this in Europe. The fluctuation range for 2030 is thus equivalent to a factor of about 2.5.

Future lithium demand for LIBs for e-mobility shown here and calculated for DERA scenarios 1 and 2 is based on the scenarios of the DERA study "Commodities for emerging technologies 2021" (Marscheider-Weidemann et al. 2021). The basis for these scenarios are the five Shared Socioeconomic Pathways (SSPs) developed from 2011

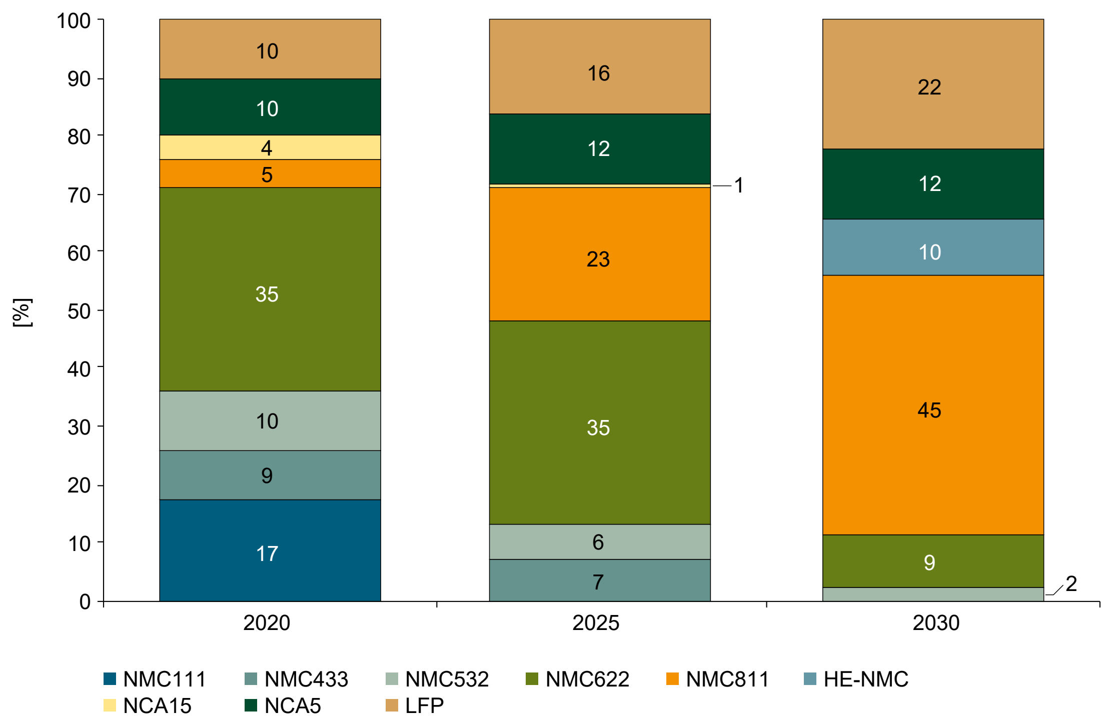

Fig. 22: Forecast development in the composition of cathodes for LIBs until 2030 (data source: modified from Marscheider-Weidemann et al. 2021, courtesy of Fraunhofer IZM 2021).

within the Fifth Assessment Report by the United Nations Intergovernmental Panel on Climate Change (IPCC; Kriegler et al. 2012). They represent different routes for global socioeconomic developments in the 21st century. This study uses the following scenarios (SSPs):

- SSP1: Sustainability – low challenges in reducing and adapting to climate change; assumed total capacity of 3,140 GWh by 2030

- SSP2: Middle of the road – intermediate challenges in damage control and adaptation; assumed total capacity of 2,004 GWh by 2030

The assumed and calculated lithium demands are based on battery technology compositions modified from Marscheider-Weidemann et al. (2021; Fig. 22).

The future lithium demands for scenario 1 (incl. SSP1 for e-mobility) and scenario 2 (incl. SSP2 for e-mobility) are shown in Table 19. The table also includes scenario 3, which is based on DERA's forecast of a global capacity of 4,500 GWh for 2030. DERA's scenario 2 represents the base case, with a demand in 2030 of around **194,648 t Li content.**

3C applications

According to Cru (2022), 3C applications including smartphones, laptops and tablets only accounted for just under 7.7 % of demand for rechargeable batteries in 2020 (5,966 t Li content). This market is generally seen as relatively saturated. The three DERA scenarios for rechargeable batteries include 3C applications with a CAGR of 5.4 % in each case. This would put demand at around **9,550 t Li content** in 2030 (Fig. 23).

Tools and e-scooters

This area includes applications such as power and gardening tools, e-bikes and trikes, and drones. Many of these used to be primarily powered by NiCd and NiMH batteries, but these older technologies are increasingly being replaced by lithium-ion batteries. As a result, growth in this area will be greater than, for instance, in 3C applications. In 2020, demand amounted to roughly 2,155 t Li content or around 2.9 % of total demand for rechargeable batteries (CRU 2022). The three DERA scenarios for rechargeable batteries include these applications with a cumulative CAGR of 22.6 %. This would put demand at around **16,500 t Li content** (Fig. 23) in 2030, with the segments drones and e-bikes the major drivers.

Renewable energy storage (ESS)

Although lithium-ion batteries compete with a wide range of other systems in stationary power storage, they are gradually becoming more important. This trend has to be seen in the context of the energy transition. Overall, this area is considered to have the highest annual growth rate potential. According to CRU (2022), demand in 2020 was around 4,780 t Li content or about 6.3 % of total demand. The three DERA scenarios for rechargeable batteries include this area of application with a CAGR of 29.1 %. With a CAGR of 42.3 % the segment residential energy storage has the highest growth. In 2030, total demand would thus reach around **60,300 t Li content** (Fig. 23).

Ceramics/glass-ceramics/glass

Little annual growth in demand of 3.8 % is forecast for the whole area ceramics/glass-ceramics/glass up to 2026 (CRU 2022). Extrapolation of

Table 19: Average future annual growth rates for lithium in LIBs for e-mobility in scenarios based on Shared Socioeconomic Pathways (SSP) 1 and 2 (Marscheider-Weidemann et al. 2021, BGR 2022, courtesy of Fraunhofer IZM 2021).

LIB demand scenario	CAGR (%) 2020–2030	Lithium demand 2020 (t Li cont.)	Lithium demand 2030 (t Li cont.)
Scenario 1[1)]	30.8	20,747	305,062
Scenario 2[2)]	26.7	18,260	**194,648**
Scenario 3[3)]	37.4	18,260	437,121

[1)] E-mobility demand = 3,140.5 GWh
[2)] E-mobility demand = 2,004.2 GWh (base case)
[3)] E-mobility demand = 4,500 GWh (DERA)

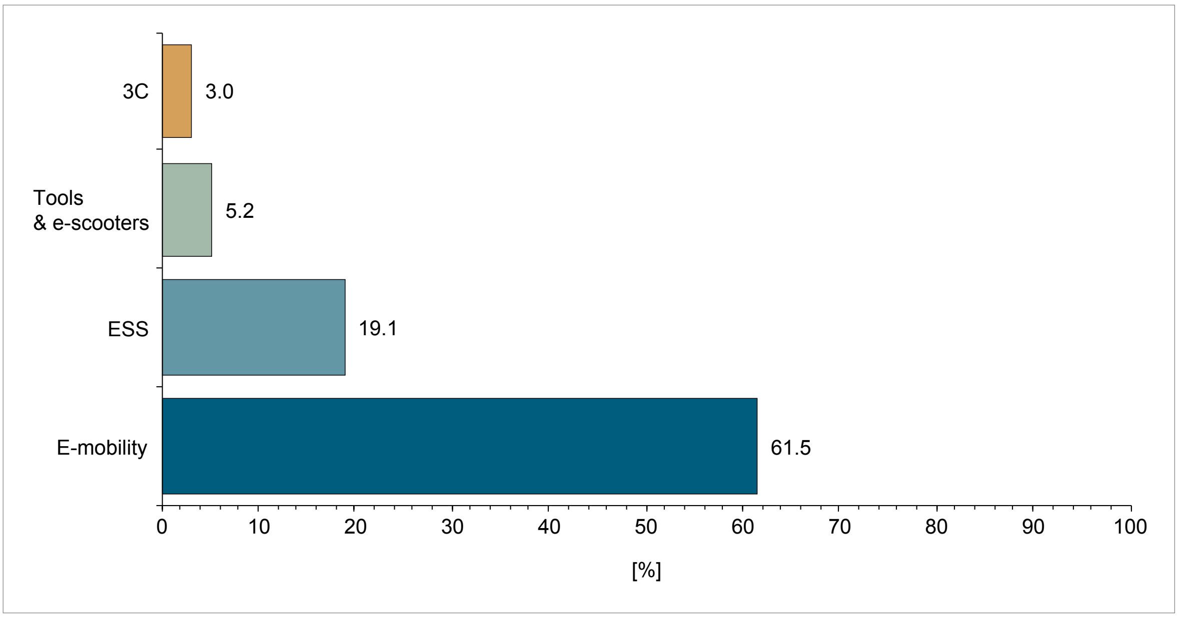

Fig. 23: Forecast lithium demand for all rechargeable battery segments in 2030 (scenario 2, base case; data source: DERA 2022, CRU 2022).

these growth rates to 2030 yields a demand of around **17,600 t Li content**. The sector would thus account for about 5.6 % of total demand, compared to a cumulative share of around 31 % in 2015 (Schmidt 2017).

Other areas of application

This area includes lubricants, metal powders, Li polymers, air treatment, non-rechargeable batteries (e. g. button cells) and aluminium production. In total, these segments accounted for about 16.7 % (12,411 t Li content) of total lithium demand in 2020 (CRU 2022). In 2015, other applications still accounted for a cumulative share of around 31 % (Schmidt 2017). A demand of about **17,660 t Li content** for this area is forecast for 2030 (scenario 2, base case). That would be equivalent to an annual growth rate of about 2.6 %. Assumptions are based on the CAGR data for the individual areas of application used by CRU (2022) for the period 2021 – 2026. The share in total demand would be just under 5.6 %. Metal powders would have the smallest growth rate and polymers the highest.

2.6.5.2 Focus on Europe (demand)

In 2020, demand in Europe was dominated by industrial applications (except batteries). According to CRU (2022), this area accounted for about 2/3 of demand (3,400 t Li content), and batteries for only about 1/3 (approx. 1,200 t Li content).

Overall, demand in Europe was low compared to the rest of the world (6 %). For industrial applications, an annual growth rate of 2.5 % is assumed for the period until 2030, equivalent to an increase in demand to about **4,150 t Li content**.

Given the cell manufacturing capacities announced for Europe, the battery sector will in future determine demand. At present, the announcements in total are equivalent to about 1,310 GWh (Pem Motion 2022). For Germany alone, manufacturing capacities of around 476 GWh are listed. Since plans by Farasis for manufacturing facilities at Bitterfeld/Wolfen have been scrapped (MZ 2022), however, planned capacities for Germany are reduced to 460 GWh or about 35 % of the figures announced for Europe as a whole (Pem Motion 2022).

The theoretical demand for batteries shown in Table 20 was calculated for 2030 based on the

Table 20: European demand forecast for 2030 (data source: CRU 2022, DERA 2022, Fraunhofer 2021).

Europe	Demand 2020 (≈ t Li cont.)[1]	Demand 2030 (≈ t Li cont.)	Demand 2030 (≈ t Li cont.)
Other applications	~ 3,400	~ 4,150	~ 4,150
Batteries	~ 1,200	~ 127,170[2, 4]	~ 72,850[3, 4]
Total	**~ 4,600**	**~ 131,325**	**~ 77,000[3, 4]**

[1] CRU 2022
[2] 100 % implementation of projects with 100 % capacity use (1,310 GWh);
[3] project total reduced to 1,000 GWh at 75 % capacity us
[4] basic data DERA 2021

cell manufacturing capacities announced. For the area “Batteries”, the calculations use European demand of **72,850 t Li content** (1,000 GWh with 75 % capacity use). Total demand for Europe is thus included at around **77,000 t Li content**, which is roughly equivalent to global lithium output in 2020.

2.6.6 Future supply/demand balance

In view of Europe’s growing importance, we will discuss two additional European supply scenarios alongside two global supply scenarios.

Supply scenario 1 (global, conservative)

This scenario is based on the following supply parameters:

- Until 2030, secondary supply will play only a minor role. In 2030, around 9,040 t Li content could be available (DERA recycling scenario 2 (25 %), Table 16).
- Global lithium mining output will not be below the figures for 2020.
- Only capacity expansion projects with an announced start of production, mines with an announced restart and mining projects under construction are included.
- Planned expansions of mining projects under construction are not included.
- Scenario 1 does not include the Bald Hill (C&M) and Whabouchi (C&M) mines.
- Expansion of the Greenbushes mine by 22,260 t Li content (TRP, CGP3) as announced by Talison Lithium is implemented as planned. CGP4 is not included because there is no schedule for it.
- The expansion projects planned by Albemarle in Chile (La Negra 3/4) and the United States (Silver Peak) are implemented as planned.
- The expansion projects planned by SQM in Chile (La Carmen processing) are implemented as planned.
- The capacity increase of Mt. Marion planned by Mineral Resources is assumed to be 10 % and implemented.
- The productive capacity planned by Mineral Resources for Wodgina from 2022 (Train 1) is included. Expansion of the productive capacity (Trains 2, 3) is not included.
- The expansion projects planned by Allkem in Argentina (Salar de Olaroz) are implemented as planned.
- The expansion in stages until 2030 planned by Livent in Argentina (Salar de Olaroz) is included in this scenario at 9,396 t Li content p.a. in 2030 (stages 1–3). Stage 4 is not included.
- Optimisation of the Pilgan plant planned by Pilbara Minerals and restart of production at the Ngungaja plant are implemented as planned. This increases capacity by 6,390 t Li content. Expansion projects P680 and P1,000 are not included.
- AMG Mining will implement the planned expansion and production of spodumene concentrates at Mibra as planned (1,100 t Li content).
- These nine expansion/restart projects are included in 2030 with a total **100 %** capacity use.

– Because of the incomplete data available for Chinese (expansion) projects, total additional output for 2030 of around 70,000 t LCE (13,150 t Li content) is assumed (100 % more than 2020).

In this scenario, an estimated additional lithium supply of around 126,730 t Li content from mining results for 2030 compared to 2020 (Table 15 and Table 16). About 208,850 t Li content from mining would then be available on the market. Total supply including secondary resources would be around 217,890 t Li content (Table 21). That is equivalent to an average annual growth rate of 10.3 %.

Between 2020 and 2030, demand is expected to grow by an annual average of 15.6–22.4 % (Table 22). Demand would thus be around 316,300–558,800 t Li content in 2030. The resulting supply shortages are shown in Table 21. These three scenarios would be rated as highly critical and are not considered very realistic. If

Table 21: Supply/demand balance in 2030 for a range of demand scenarios and supply scenario 1 (conservative).

Scenario	CAGR 2020–2030 (%)	Supply 2030 (t Li cont.)	Demand 2030 (t Li cont.)	Supply/demand balance (t Li cont.)[1)]	Supply/demand balance (%)[1)]
1	19.1		426.700	**–208,832**	**–95.8**
2	15.6	217,890	316,300	**–98,418**	**–45.2**
3	22.4		558,800	**–340,891**	**–156.5**

[1)] Slight deviations possible due to rounding

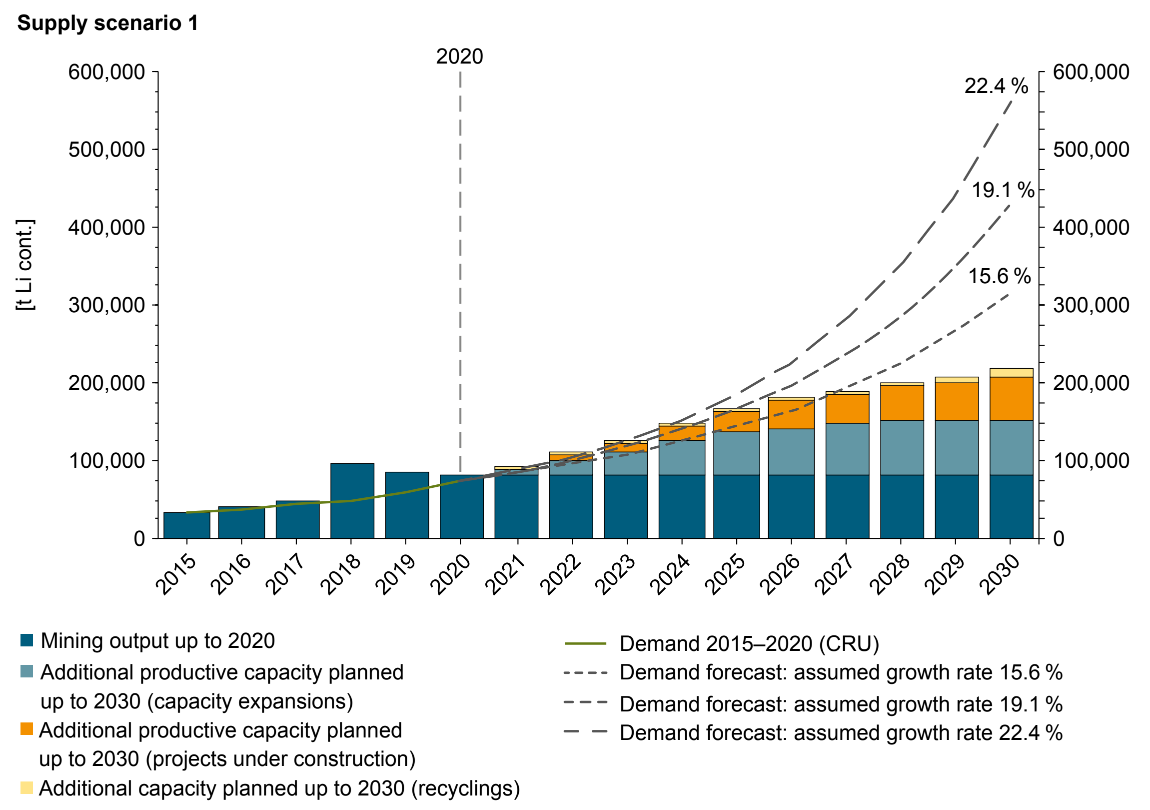

Fig. 24: Scenarios for the development of lithium supply and demand until 2030 (supply scenario 1, conservative; data source: BGR 2022, CRU 2022).

supply were to develop until 2030 as assumed in scenario 1, the maximum rate of demand growth at which market equilibrium could be maintained would be about 11.4 %.

Supply scenario 2 (global, optimistic)

This scenario is based on the following supply parameters:

- Until 2030, secondary supply will play only a relatively minor role in this scenario. In 2030, around 27,120 t Li content could be available (DERA recycling scenario 2 (75 %), Table 16).
- Global lithium mining output will not be below the figures for 2020.
- Capacity expansion/restart projects and projects with the status (PFS/DFS) are included.
- Scenario 2 includes the Bald Hill (C/M) and Whabouchi (C/M) mines.
- The expansion projects announced by Talison Lithium (TRP, CGP3) are implemented as planned. As there is no schedule, CGP4 is included from 2028 with a reduced total capacity in 2030.
- The expansion projects planned by Albemarle in Chile (La Negra 3/4) and the United States are implemented as planned.
- The expansion projects planned by SQM in Chile (La Carmen) are implemented as planned.
- The capacity increase of Mt. Marion planned by Mineral Resources is assumed to be 15 % and implemented.
- The productive capacity planned by Mineral Resources for Wodgina from 2022 (Train 1) is included. As there is no schedule for the projects to increase productive capacity (Trains 2, 3), they are included from 2028 with a reduced total capacity in 2030.
- The expansion projects planned by Allkem in Argentina (Olaroz) are implemented as planned.
- The expansion in stages by 2030 planned by Livent in Argentina (Olaroz) is included in this scenario (stages 1–3). Stage 4 is included from 2029 with a reduced capacity in 2030.
- The optimisation of the Pilgan plant planned by Pilbara Minerals and restart of production at the Ngungaja plant are implemented as planned. The P680 and P1,000 expansion projects are included from 2028/2029 with reduced capacity in 2030.
- AMG Mining will implement the planned expansion and production of spodumene concentrates at Mibra as planned (1,100 t Li content).
- The following advanced exploration projects with the status PFS/DFS are also included in this scenario, some of them with reduced total productive capacity in 2030: 3Q (Neo Lithium), Kachi (Lake Resources). Pastos Grandes (Millennial Lithium), Kathleen Valley (Liontown), Maricunga (Lithium Power), Upper Rhine Graben (Vulcan Energy), Zinnwald (Zinnwald Lithium), Wolfsberg (European Lithium), Keliber (Keliber Oy), NAL/Authier (Sayona/Piedmont), James Bay (Allkem), Rose Tantalum (Critical Elements), Georgia Lake (Rocktech Lithium), Sonora (Bacanora), Jadar (Rio Tinto), Mina de Barroso (Savannah Resources), St. Jose (Infinity Lithium), Karibib (Lepidico), Arcadia (Prospect Resources), Manono (AVZ Minerals), Goulamine (Mali Lithium), Cinovec (European Metals), Ryolite Ridge (Ioneer), Carolina (Piedmont Lithium), Thacker Pass (Lithium Americas), Smackover (Standard Lithium), Hells Kitchen (CTR).
- As in scenario 1, the expansion/restart projects are included in 2030 with a total **100 %** capacity use.

Table 22: Supply/demand balance in 2030 for a range of demand scenarios and supply scenario 2 (optimistic).

Scenario	CAGR 2020–2030 (%)	Supply 2030 (t Li cont.)	Demand 2030 (t Li cont.)	Supply/demand balance (t Li cont.)[1)]	Supply/demand balance (%)[1)]
1	19.1	357,680	426.700	**–69,041**	**–19.3**
2	15.6		316,300	**41,373**	**11.6**
3	22.4		558,800	**–201,100**	**–56.2**

[1)] Slight deviations possible due to rounding

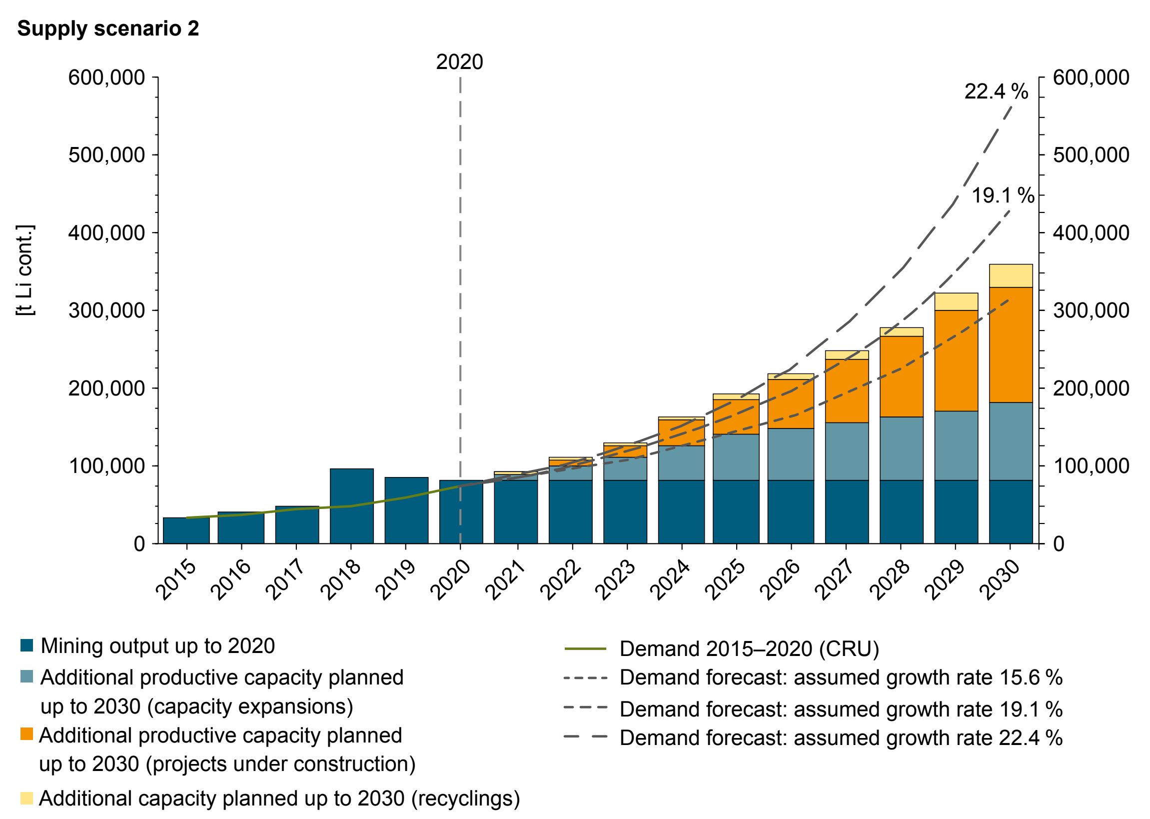

Fig. 25: Scenarios for the development of lithium supply and demand until 2030 (supply scenario 2; data source: BGR 2022, CRU 2022).

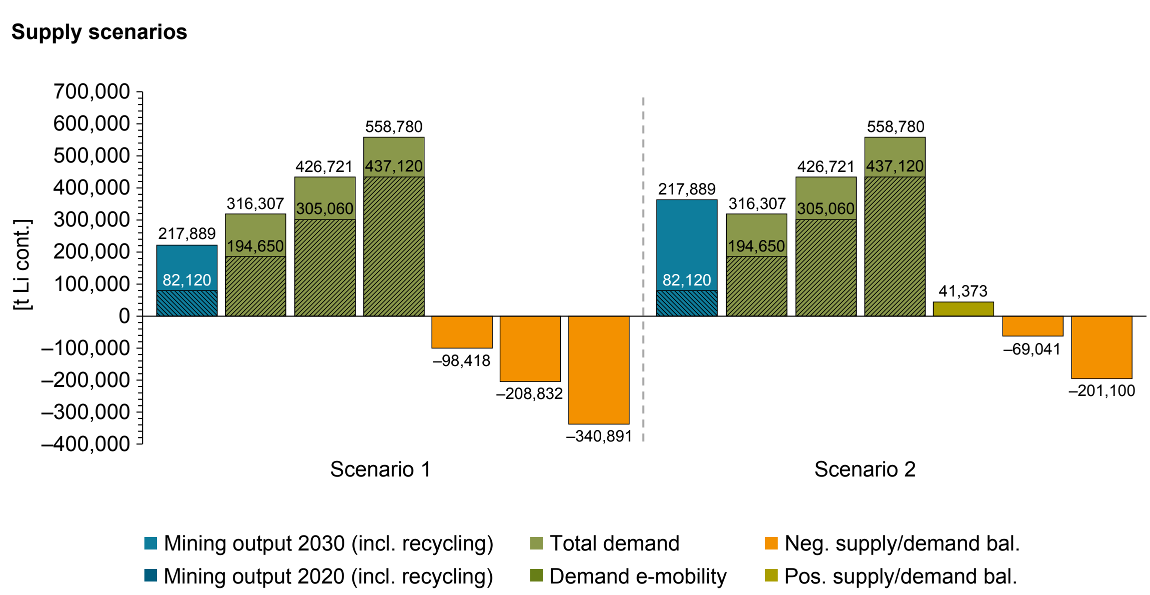

Fig. 26: Comparison of scenarios for the development of supply and demand and supply/demand balance (data source: BGR 2022, CRU 2022).

- The projects listed here (PFS/DFS) are included up to 2030 with **70 %** use of the total capacity assumed in each case.
- Because of the incomplete data available for Chinese (expansion) projects, total additional output for 2030 of around 70,000 t LCE (13,150 t Li content) is assumed (100 % more than 2020).
- No potential in Bolivia is included in the scenario up to 2030.

In this scenario, an estimated additional lithium supply of around 248,446 t Li content from mining results for 2030 compared to 2020. About 330,563 t Li content from mining would then be available on the market. If secondary resources were included, the figure would be around 357,680 t Li content. That is equivalent to an average annual growth rate (CAGR) of 15.8 %.

Between 2020 and 2030, demand is expected to grow by an annual average of 15.6 – 22.4 %. Demand in 2030 would thus be around 316,300 – 558,800 t Li content. For the three different demand scenarios in Table 22, scenarios 1 and 3 result in clear supply shortages with a negative supply/demand balance of –19.6 % and –56.6 %. The market situation would in this case be rated as highly critical. Only scenario 2 results in excess supply of 40,527 t Li content.

If supply were to develop until 2030 as assumed in scenario 2, the maximum rate of demand growth at which market equilibrium could be maintained would be about 17 %.

Supply scenario Europe (optimistic)

In this scenario, the focus is on Europe's potential self-sufficiency. The scenario is based on the following supply parameters:

- **The scenario includes only European projects (self-sufficiency).**
- The parameters for project implementation are the same as for global supply scenario 2 (70 % of the total capacity assumed in each case).
- Only projects with the status PFS/DFS (completed/ongoing) are included.
- The scenario includes only primary projects and no refinery capacities based on commodity imports.
- It does not include capacities that are purely for the processing of imported precursors.
- Supply from recycling is included as appropriate (Table 17).

In this scenario, an estimated lithium supply of around 18,542 t Li content from European mining results for 2030. An additional 2,570 – 7,710 t Li content would be available from recycling, depending on the recycling rate. About 21,112 – 26,252 t Li content from European sources would then be available on the market.

Between 2020 and 2030, lithium demand in Europe is expected to grow by an annual average of 32.5 % (1,000 GWh at 75 % capacity use). Demand would thus be around 77,000 t Li content in 2030. Lithium-ion batteries account for about 72,850 t Li content.

For both supply scenarios for Europe in Table 23, clear supply shortages with a negative supply/demand balance result. In both cases, the market situation would be rated as highly critical, since these supply shortages would have to be met from imports.

If supply were to develop until 2030 as assumed in scenario 1, the maximum rate of demand growth at which market equilibrium could be maintained would be about 16.5 %. For scenario 2, the figure is around 19 % and thus only slightly higher. Subtracting other areas of demand, about 16,962 t Li content (scenario 1) or 22,100 t Li content (scenario 2) would theoretically be available for lithium-ion batteries alone.

These European supply quantities would therefore be sufficient only for a cell manufacturing capacity of 170 – 230 GWh. With these supply quantities and this demand scenario, Europe could itself meet 27 – 34 % of its demand in 2030. Most of the required lithium would have to be imported.

The assumptions made here for Europe do not take into account that many of the cell manufacturing capacities announced for Europe belong to Asian companies, which already have access to lithium or its intermediate products. Announced processing capacities based on commodity imports are not taken into account either.

Table 23: Supply/demand balance 2030 for a range of supply scenarios for Europe.

Scenario	Supply 2030 (t Li cont.)	Demand 2030 (t Li cont.)	Supply/demand balance (t Li cont.)[1]	Supply/demand balance (%)[1]
1[2]	21,110	77,000[4]	**–55,890**	**–265**
2[3]	26,250		**–50,750**	**–193**

[1] Rounded
[2] includes recycling at a 25 % recycling rate
[3] includes recycling at a 75 % recycling rate
[4] based on European cell manufacturing capacities of 1,000 GWh at 75 % capacity use.

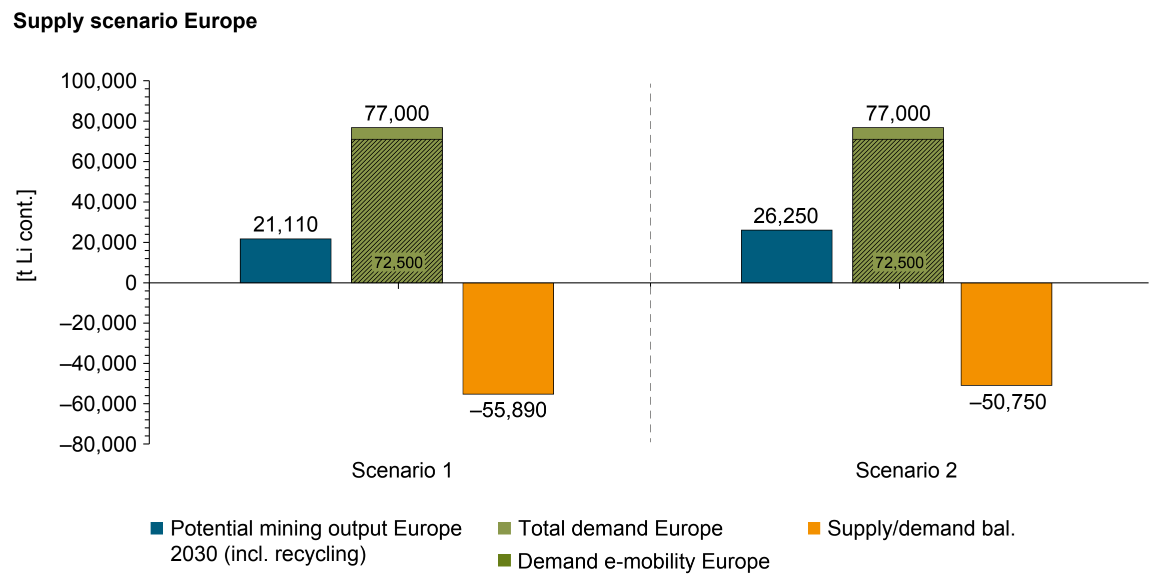

Fig. 27: Supply and demand scenario Europe 2030 (data source: BGR 2022, CRU 2022).

2.6.6.1 Geopolitical risk of future supply

Taking the global supply scenario 1 as a basis, the country concentration in lithium mining in 2030 is only slightly different to the reference year 2020. The HHI would fall from 3,338 in 2020 to 2,795 in 2030.

Australia's share in global supply would thus be around 42.7 % (2020 = 48.3 %). While Chile's share would decline from 26.2 % (2020) to 19.3 %, Argentina's share would rise from 7.2 % (2020) to almost 20.6 % in 2030. China's share would fall from 16.2 % (2020) to about 12.7 %. China's share in primary production in particular is hard to estimate, because of incomplete data. Canada's share would rise from zero to about 8.3 %. The three largest mining and producer countries would account for around 82.6 % in 2030 (Fig. 28).

The weighted country risk, calculated using the World Bank's indicators for 2020, would be 0.74 in 2030, lower than in 2020 and thus in the uncritical range.

If supply develops as shown in supply scenario 2, the country concentration for lithium mining will be significantly different in 2030. The HHI by country would fall from 3,338 in 2020 to 1,945 in 2030 because of the much wider range of supply.

Australia's share in global supply would be around 37 % (2020 = 48.3 %) in this scenario. Chile's share would decline from 26.2 % (2020) to 12.8 % (2030), because of the small number of projects in the country due to planning uncertainties in the lithium sector. Argentina's share, on the other hand, would rise from 7.2 % (2020) to about 16.9 % in 2030. China's share in 2030 would be around 6.8 %. Canada would increase its share from zero to about 4.3 % in 2030. Mali (3 %) and DR Congo (4.1 %) would join the market as major new supplier countries. The United States would also be able to increase their share from 0.5 % (2020) to around 4 % in 2030 (Fig. 28).

The weighted country risk, calculated using the World Bank's indicators for 2020, would be 0.69 in 2030 and thus in the uncritical range.

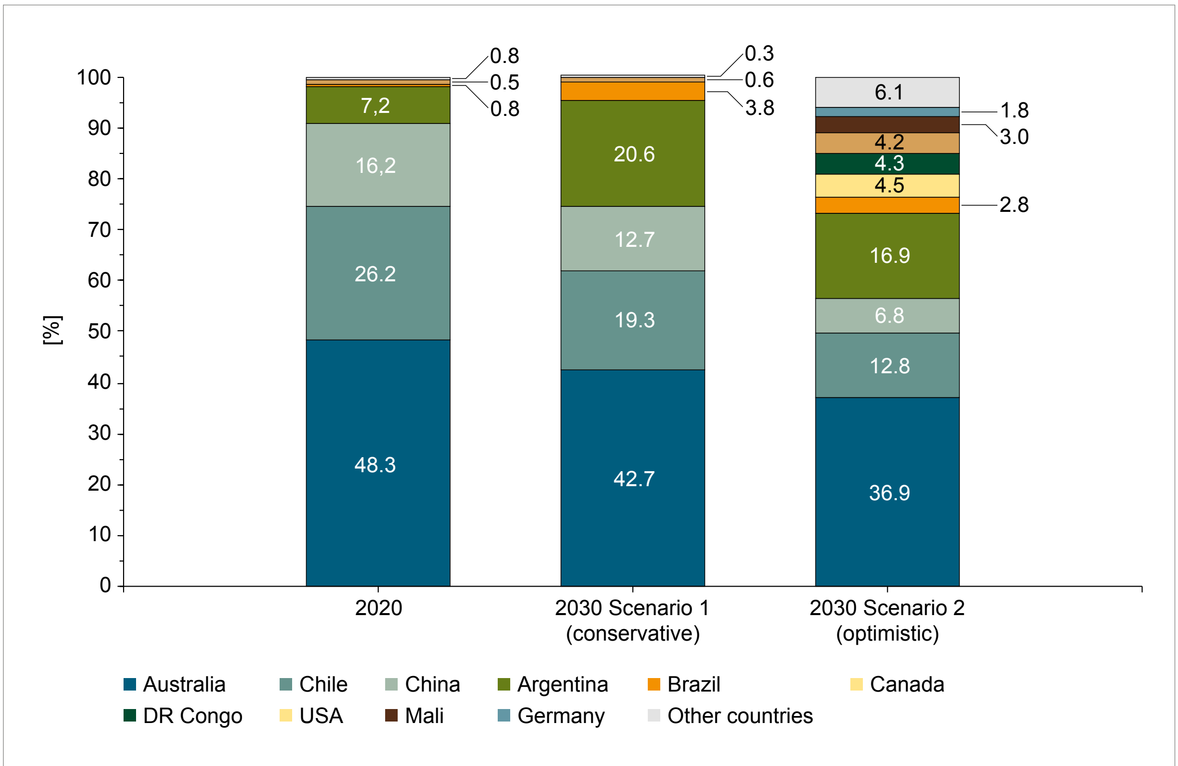

Fig. 28: Change in the country concentration for mining up to 2030 (data source: CRU 2022, DERA 2022).

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Appendix

Indicators and risk assessment for lithium

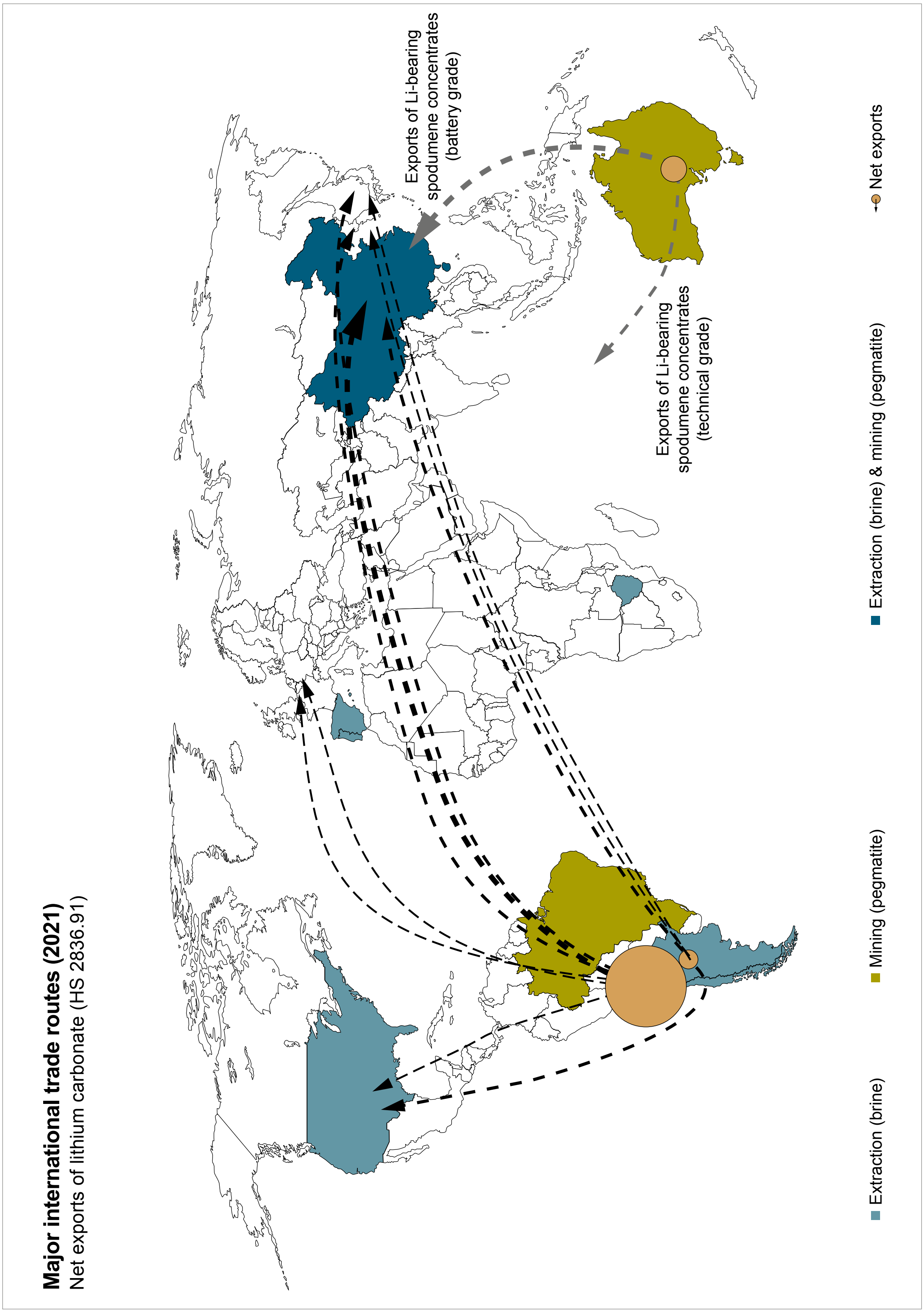
Indicator			Score		Risk trend
Supply and demand			**2015**	**2020**	
Recycling rate	Lithium	**EOL-RR**	< 0.1 %	< 0.1 %	→
Current supply/demand balance	Lithium	**S/D**	–0.8 %	–5.2 %	↗
Country concentration of production	Mining output	**HHI**	3,033	3,338	→
Weighted country risk of production	Mining output	**WCR**	0.95	0.67	↗
Industry concentration	Mining companies	**HHI**	2,446	1,206	↘
Trade			**2015**	**2021**	
Global net exports					
Diversification	Lithium carbonate	**HHI**	6,597	6,948	→
Weighted country risk	Lithium carbonate	**WCR**	0.83	0.70	→
Diversification	Lithium oxide/hydroxide	**HHI**	3,200	4,914	↗
Weighted country risk	Lithium oxide/hydroxide	**WCR**	0.53	0.05	↗
Diversification	Lithium chloride	**HHI**	5,927	5,327	→
Weighted country risk	Lithium chloride	**WCR**	0.05	–0.20	↗
Diversification	Spodumene concentrate	**HHI**	8,372	8,855	→
Weighted country risk	Spodumene concentrate	**WCR**	1.31	1.37	→
Diversification	Lithium-ion batteries	**HHI**	4,353	2,575	↘
Weighted country risk	Lithium-ion batteries	**WCR**	0.96	0.51	↗
Net imports Germany					
Diversification	Lithium carbonate	**HHI**	3,532	3,246	→
Weighted country risk	Lithium carbonate	**WCR**	1.17	0.95	→
Diversification	Lithium oxide/hydroxide	**HHI**	3,373	5,401	↑
Weighted country risk	Lithium oxide/hydroxide	**WCR**	1.19	1.47	↘
Diversification	Lithium-ion batteries	**HHI**	1,804	2,339	↗
Weighted country risk	Lithium-ion batteries	**WCR**	0.58	0.47	→
Resources			**2015**	**2020**	
Extent of exploration					
Lifespan indicator	Primary lithium	**Lk**	440	273	↗
Investments in exploration	Primary lithium	**IE**	–	–	
Reserven					
Country concentration of reserves	Lithium	**HHI**	3,490	2,628	↘
Weighted country risk of reserves	Lithium	**GLR**	0.55	0.74	↘

Indicator			Score	Risk trend
Future supply			**2030**	
Supply scenario 1				
Country concentration of future mining	Primary lithium	**HHI**	2,886	
Weighted country risk of future mining	Primary lithium	**WCR**	0.97	
Supply scenario 2				
Country concentration of future mining	Primary lithium	**HHI**	2,447	
Weighted country risk of future mining	Primary lithium	**WCR**	0.84	
Zukünftige Marktdeckung			**2030**	
Supply scenario 1				
Future supply/demand balance (FS/D) until 2030	Growth in demand **19.1 %** p. a.	**FS/D**	–95.8	
	Growth in demand **15.6 %** p. a.		–45.2	
	Growth in demand **22.4 %** p. a.		–156.5	
Supply scenario 2				
Future supply/demand balance (FS/D) until 2030	Growth in demand **19.1 %** p.a.	**FS/D**	–19.3	
	Growth in demand **15.6 %** p.a.		11.6	
	Growth in demand **22.4 %** p.a.		–56.2	

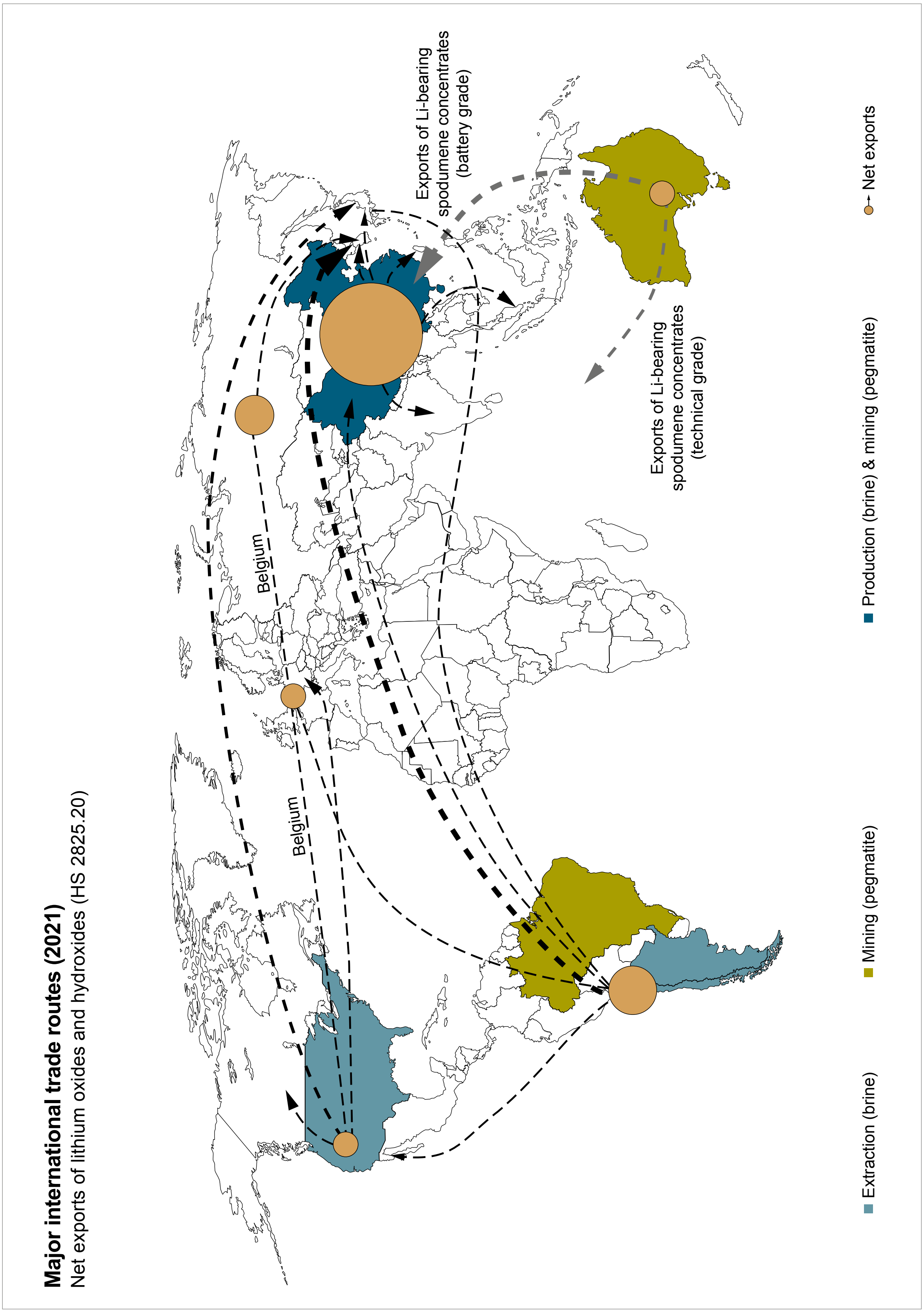
Glossary

Diversification of imports	The diversification of imports is calculated using the HHI, based on the quantity sourced from each country expressed as a share of total imports.
Industry concentration	Industry concentration is calculated using the HHI, based on the respective share of total global output produced by each mining company.
Weighted country risk	The weighted country risk (WCR) is calculated by multiplying the individual countries' shares of output, net exports or German imports by their respective country risk (CR) and summing the results. The weighted country risk is in the range +2.5 to –2.5. Values above +0.5 are rated as low risk, those between +0.5 and –0.5 as moderate risk, and values below –0.5 are considered critical.
Herfindahl-Hirschman index (HHI)	The Herfindahl-Hirschman index (HHI) is a measure of a market's industry concentration. It is calculated by squaring the market share of each competitor in the market and then summing the resulting figures. Based on the scale set by the U.S. Department of Justice and the Federal State Commission, markets with an HHI below 1,500 are defined as having a low concentration, and with a score between 1,500 and 2,500 points as moderately concentrated. Markets with an index score above 2,500 are considered highly concentrated.
Country concentration	Country concentration is calculated using the HHI based on the annual value of each country's shares in mining output, refinery output or global net exports.
Country risk	The country risk (CR) is the average of the six Worldwide Governance Indicators of the World Bank, which annually rates the governance of more than 200 countries around the globe. The indicators measure (1) voice and accountability, (2) political stability and absence of violence, (3) government effectiveness, (4) regulatory quality, (5) rule of law, and (6) control of corruption.
Lifespan indicator	The lifespan indicator is determined from the ratio of current reserves to current global mining output. The lifespan indicator (static range) indicates the extent of exploration and the necessity of future exploration activities. It does not indicate the time of exhaustion of a natural resource.
Supply/demand balance	The supply/demand balance is determined from the ratio of demand (refinery consumption) to supply (refinery output). Rating scale: < 0 % = critical, 0 %–10 % = moderate, > 10 % = uncritical
Net exports	The term net exports refers to the difference between an economy's exports and imports. Net exports can be either positive or negative. This study uses positive net exports (NX > 0) for the individual commodities, since the focus is on the supply side. Negative net exporters are consumer countries (net importers) of the relevant resources. The sum of positive net exports thus represents the output volumes that enter international trade.
Recycling rate (EOL-RR)	The end-of-life recycling rate (EOL-RR) is the ratio of the volume of old scrap of a resource that enters recycling to the total volume of the resource theoretically available in end-of-life products. Rating scale: < 10 % = critical, 10 %–50 % = moderate, > 50 % = uncritical.
Reserves	Reserves are the volumes of resources that are economically viable assuming current prices and current technology.
CAGR growth rates	Growth rates are based on the compound annual growth rate (CAGR). This represents the average percentage by which the starting value in a time series grows to hypothetical values for the reporting years until the actual end value of the time series is reached. It ignores actual fluctuations in any year during the period considered.
Future supply/demand balance	The future supply/demand balance is determined from the ratio of future demand to future supply. Two scenarios are developed for future supply and two for future demand. Future supply is calculated from total current mining output plus an additional annual productive capacity from new mining projects.

International trade (net exports)



International trade routes in 2015 (net exports of lithium carbonate; data source: IHS Markit 2022).



International trade routes in 2015 (net exports of lithium oxide/hydroxide; data source: IHS Markit 2022).

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