BRIEFING - September 2024

Unlocking lithium’s potential

How to do it sustainably in Europe

Summary

Europe has much lithium potential, but focus and policy is needed to develop it sustainably

As lithium demand is expected to rise driven by the global shift towards transport electrification and energy storage systems, key questions emerge: What are the key trends shaping the lithium market? What are the environmental challenges associated with lithium production and how can they be mitigated? In this paper, T&E answers these questions and provides policy recommendations to advance sustainable practices in lithium production.

The key developments shaping the global and European lithium markets are:

- As a critical element in all lithium-ion battery chemistries, whether NMC, LFP or other, lithium will be needed in batteries for a long time, with global lithium demand projected to more than double to 2.5 Mt LCE (lithium carbonate equivalent) by 2030.
- Chile, Australia, Argentina and China account for 80% of the known global lithium reserves. The EU is a net importer of lithium, sourcing lithium carbonate and hydroxide largely from Chile, China and the US.
- While Australia, China and Chile currently dominate lithium extraction and the processing is concentrated in China, by 2030, other countries in the Americas, Africa and Europe will increasingly play a role in the market (accounting for 37% of global mined production and 24% of refined production in 2030).
- However, with 28 mining, refining and integrated projects in the pipeline, Europe could reduce its import reliance by 2030, meeting 53% of demand with mined output and potentially achieving self-sufficiency in processed lithium.

Lithium production comes with carbon and water footprints, depending on source, region and process deployed. A recent life cycle assessment (LCA) by Minviro, commissioned by T&E, examined the carbon and water intensity of lithium hydroxide monohydrate production for nickel-based lithium-ion batteries. The study analysed six distinct production operations - existing and prospective - across Germany, Portugal, Australia and China. Some of the key findings are:

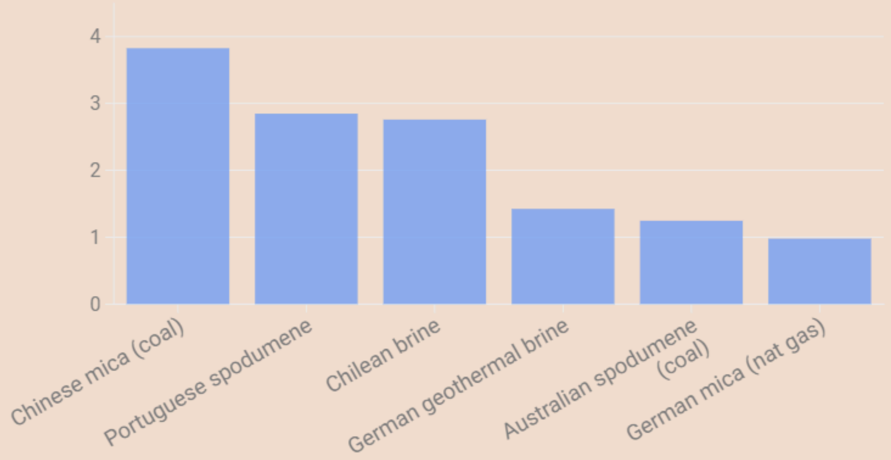
- Direct Lithium Extraction (DLE) from geothermal brine in Germany stands out as the most environmentally friendly, generating 83% fewer emissions than the most carbon-intensive method, lithium extraction from Chinese hard rock mica. Spodumene-based production in Australia and Portugal have a moderate impact, due to energy-intensive processes, though Portugal fares better owing to a cleaner energy mix.
- German mica production and DLE from geothermal brine have relatively low direct water use, which is further supported by Germany's low water scarcity factor. When comparing brines, DLE is 50% less water-intensive than Chilean brine. The water intensity of the Portuguese spodumene route is exacerbated by Portugal’s higher water scarcity factor and

reagent use (e.g. sulfuric acid). Chinese mica production has the highest water use among the routes analysed, being 4 times higher than the German mica route and nearly 3 times higher than the DLE route.

While the LCA highlights the complexity of environmental impacts across various lithium production routes, there are solutions that can mitigate them. Carbon footprints can be reduced through renewable energy, innovation and process efficiency, while water impacts can be addressed by implementing new technologies such as DLE, recovery and recycling technologies, closed loop systems and tailings dewatering techniques. In arid coastal regions, desalination could be an option if combined with energy-efficient technologies and best waste management practices.

Water use in lithium hydroxide monohydrate production

Water intensity ratio per kg LHM



Source: Minviro • Note: LHM refers to lithium hydroxide monohydrate ($LiOH \cdot H_2O$). Results are presented as a ratio of lowest climate change impact route. The Australian spodumene route includes mining in Australia and refining in China.

To scale domestic lithium production sustainably, the European Commission should back Strategic Projects under its Critical Raw Materials Act that employ innovative technologies and adhere to best emissions, water, waste management and biodiversity practices. As part of the EU taxonomy for sustainable activities, the European Commission should set “low emission” lithium thresholds to attract private capital, i.e. T&E recommends 10 kg CO2e/kg lithium hydroxide monohydrate by 2030. Governments and businesses should also accelerate investments in energy-efficient, water-saving technologies, which can be exported globally.

Acronyms

CO2e - carbon dioxide equivalent

DLE - direct lithium extraction

ESS - energy storage systems

EV - electric vehicle

GHG - Greenhouse gas emissions

GWh - gigawatt-hour

IRMA - The Initiative for Responsible Mining Assurance

kt - kilotonnes

kWh - kilowatt-hour

LCA - Life Cycle Assessment

LCE - lithium carbonate equivalent

LFP - lithium iron phosphate

Li - lithium

LHM - lithium hydroxide monohydrate

LMFP - lithium manganese iron phosphate

LMR-NMC - lithium-manganese rich nickel manganese cobalt oxide

LNMO - lithium nickel manganese oxide

Mt - million tonnes

NCA - lithium nickel cobalt aluminium oxide

NMC - lithium nickel manganese cobalt oxide

NMCA - lithium nickel manganese cobalt aluminium oxide

eLNO - enhanced lithium nickel oxide

ZLD - Zero Liquid Discharge

1. Introduction

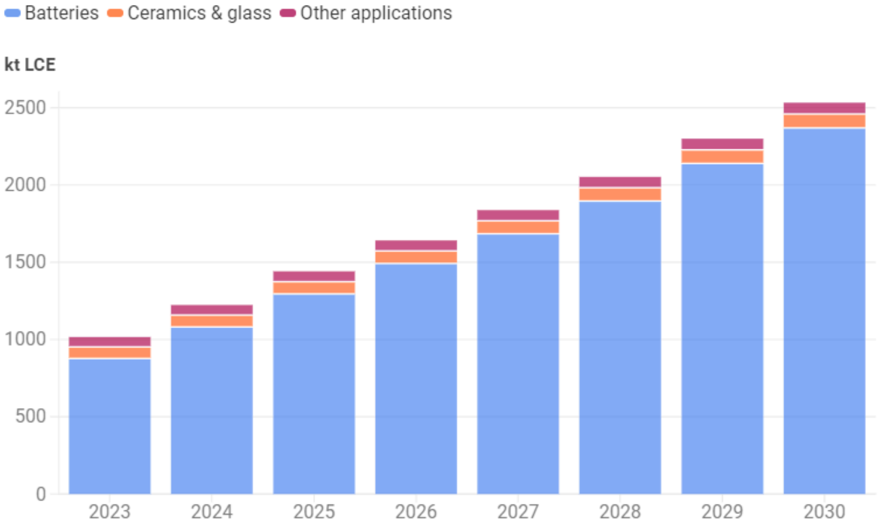
Given the necessity to electrify road transport to hit EU's and global climate targets, demand for some critical minerals - while significantly less the volumes currently extracted for oil and gas - will increase. Lithium, a core element of lithium-ion batteries, is expected to see its global demand more than double by 2030.[1] If done without strong environmental stewardship, extracting and processing lithium can come with serious environmental concerns, notably greenhouse gas (GHG) emissions and water use.

In this report, T&E explores the trends of the global and European lithium markets, along with challenges and opportunities in lithium extraction and processing, particularly around emissions and water management. The report concludes with policy recommendations to promote sustainable lithium production and strengthen Europe's supply chain as demand for batteries from electric vehicles and energy storage rises.

2. The global lithium market

2.1 Demand

Lithium has traditionally been used in a range of industries from glass and ceramics to lubricants though metallurgy, air conditioning and medical. However, nowadays, batteries represent the largest and fastest growing application, driven by the global push towards transport electrification and the widespread adoption of energy storage systems. By 2030, global lithium demand is expected to more than double to 2.5 Mt LCE (lithium carbonate equivalent) from around 1 Mt LCE in 2023, with batteries accounting for 94%.[2]



Global lithium demand by application

Source: Wood Mackenzie • Note: Including batteries from EVs, ESS, micro-mobility, electronics, power devices and other products.

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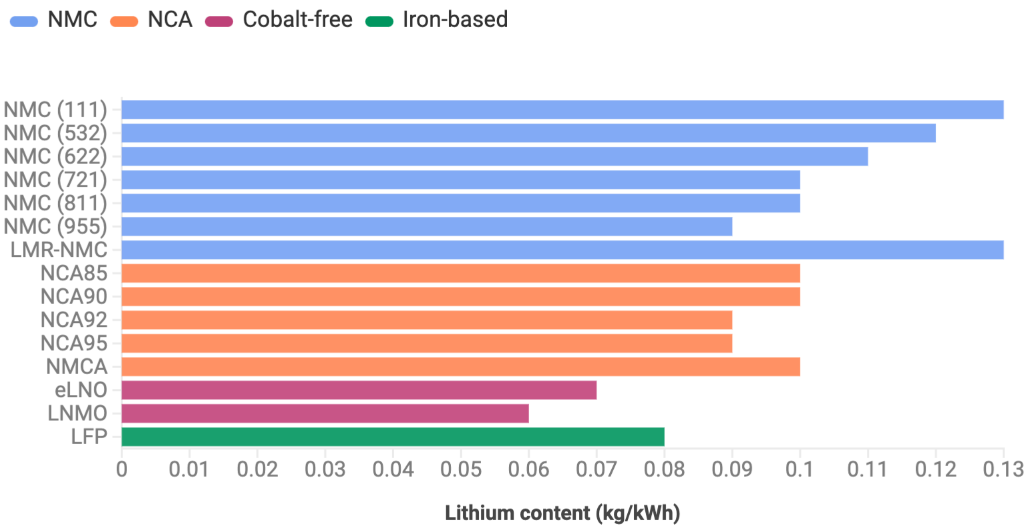
[1] Wood Mackenzie (28.06.2024). "Global electric vehicle & battery supply chain risked EV outlook - Q2 2024". URL

[2] Wood Mackenzie (28.06.2024). "Global electric vehicle & battery supply chain risked EV outlook - Q2 2024". URL

In lithium-ion batteries, lithium is found in the cathode material, providing the ions that move between the cathode and anode during the charging and discharging process.

While the content of other metals in battery cathodes such as nickel and cobalt have changed significantly over the past decade, the lithium content remained relatively stable, showing a slight decrease over time, e.g. between 0.9 and 0.13 kg Li/kWh for NMC and NCA chemistries, which are the preferred chemistries for long range and performance EVs. In comparison to these nickel-containing chemistry families, LFP - used predominantly in energy storage systems, buses and entry level passenger cars - contains lower lithium amounts, implying that diversification towards LFP batteries would result in slightly lower demand for lithium.



Lithium content in cathode chemistries

Source: BloombergNEF

Volatile price dynamics of lithium of the past several years have accelerated the development of lithium-free batteries, such as the lower cost sodium-ion batteries, which can alleviate supply bottlenecks in the lithium market. Nonetheless, in the medium term, sodium-ion batteries are expected to marginally substitute lithium, mainly in energy storage systems and smaller electric vehicles, with lithium continuing to dominate the battery market.

A more important factor contributing to the uncertainty of lithium demand in the longer term is the rate of adoption of solid-state batteries. These batteries, which are still under development, offer enhanced safety, longer driving ranges and faster charging times. In terms of chemical composition, solid-state batteries have cathodes similar to those in traditional lithium-ion batteries (NMC, NCA, LFP), but they require additional lithium for their solid electrolytes and anodes, increasing lithium intensity by 25%-50% per kWh. Nonetheless, BloombergNEF forecasts that this technology will not achieve mass adoption until after 2030, thereby limiting its impact on lithium demand until then.[3] Consequently, solid-state batteries have not been included in the scope of this report.

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[3] BloombergNEF. (14.04.2021). "A route for solid-state battery adoption: Europe and the U.S.". URL

Overall, by 2030, iron-based chemistries (LFP, LMFP) are projected to account for 63% of global demand for EV and ESS batteries, reflecting updated forecasts.[4] Nickel-containing chemistries are expected to make up for 35%, while sodium-ion batteries will capture the remaining 3%.

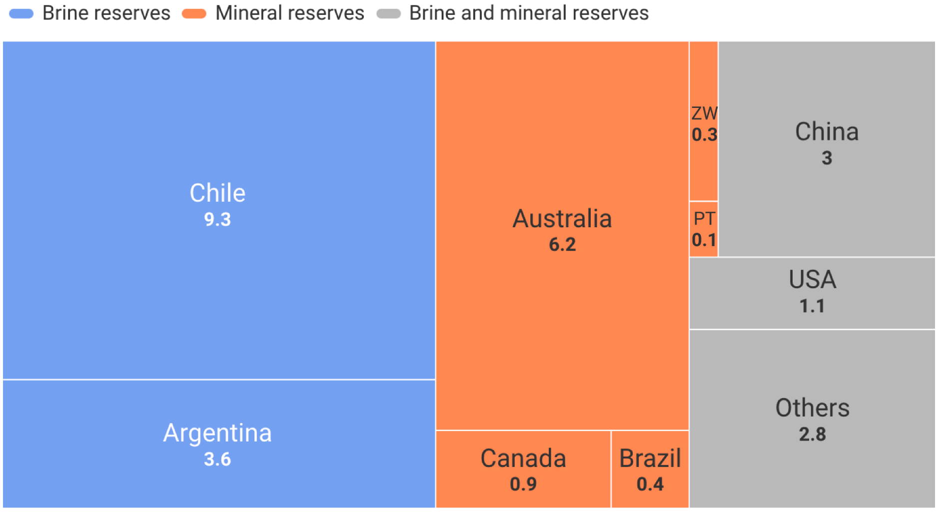
2.2 Supply

Lithium has been traditionally extracted from two sources: hard rock deposits such as spodumene in Australia, and brines found in the salt flats of South America.

Chile is home to around a third of the world's lithium reserves, followed by Australia with around a fifth, and Argentina and China. Altogether the four countries account for 80% of the known global lithium reserves.

Lithium global reserves

(Total: 27.7 Mt lithium content)



Source: U.S. Geological Survey 2024

Hard rock mining, which accounts for 60% of global lithium supply, is a highly industrialised process involving complex, energy-intensive production steps and chemical usage, with high recovery rates. In contrast, lithium extraction via natural brine evaporation in ponds, making up for 40% of global supply, is less energy-intensive and relatively inexpensive, but is a slow process (taking up to 18 months to produce battery-grade products), has a larger water and land footprint than extraction from hard rock.

Australia, China and Chile currently dominate lithium extraction from minerals and brines, collectively accounting for 85% of global supply. In 2023, these three countries produced 925 kt LCE out of a global total of 1.1 Mt LCE.[5] Australia primarily produces spodumene concentrate, which is shipped to China for chemical processing; Chile focuses on lithium extraction from brine, while China sources lithium from both brines (despite challenges posed by high magnesium content) and minerals like spodumene and more recently lower-grade mica lepidolite.

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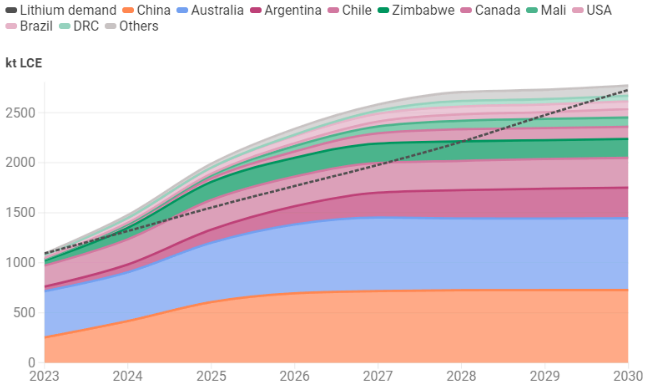
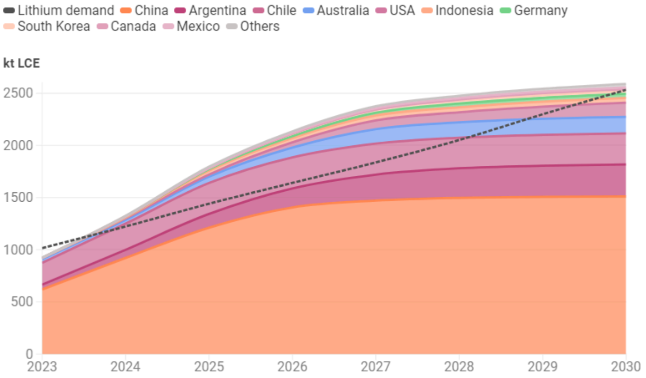
[4] BloombergNEF. (18.07.2024). “Lithium-Ion Batteries: State of the Industry 2024”. URL

[5] Wood Mackenzie (28.06.2024). “Global electric vehicle & battery supply chain risked EV outlook - Q2 2024”. URL

By 2030, global mined production is projected to more than double to 2.8 Mt LCE.[6] While the top 3 countries will continue to lead, they will lose some market share to emerging producers such as Argentina (expected to rival Chile), Zimbabwe, Canada, Mali, the US, Brazil and others, with these emerging countries collectively accounting for 37% of the market by 2030. Notably in Africa, investments are largely driven by Chinese companies.


Top 10 lithium mining countries

Source: Wood Mackenzie • Note: Lithium production from mineral and brine sources


Top 10 lithium refining countries

Source: Wood Mackenzie • Note: Lithium refined production from mineral and brine sources. Excluding recycling

On the refining side, today most of the capacity is concentrated in China, which accounted for 67% of global supply in 2023. However, countries like Argentina, the US and Australia plan to scale up lithium refining operations in the coming years. By 2030, global production of refined lithium (excluding recycling) is expected to reach 2.6 Mt by 2030 from 925 kt in 2023, driven by capacity expansions both in China and ex-China.[7]

Refined lithium products

The two main lithium product forms used in lithium-ion batteries are lithium carbonate and lithium hydroxide. Lithium carbonate is typically sourced from brines and employed in LFP batteries. Conversely, lithium hydroxide is primarily sourced from hard rock minerals and is preferred in high energy density, nickel-based batteries. Additionally, lithium carbonate can undergo further processing to be converted into lithium hydroxide.[8]

Apart from lithium-ion cathode applications, lithium chloride is used to produce lithium metal for the anode of some solid-state batteries.

Furthermore, non-battery applications of lithium include lithium carbonate in glass and ceramics, cement and medications; lithium hydroxide in lubricants; lithium bromide in air-conditioning systems; lithium fluoride in aluminium smelting; lithium metal in alloy making for the aerospace industry.[9]

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[6] Wood Mackenzie (28.06.2024). “Global electric vehicle & battery supply chain risked EV outlook - Q2 2024”. URL
[7] Wood Mackenzie (28.06.2024). “Global electric vehicle & battery supply chain risked EV outlook - Q2 2024”. URL
[8] BloombergNEF (25.03.2019), “Lithium-ion batteries: A 101 Guide”. URL
[9] International Lithium Association, “Lithium - Other chemical applications”. URL

2.2.1 Future supply developments

Going forward, there is a growing focus on developing more sustainable and cost-effective lithium production routes. A suite of new technologies, known under the umbrella term as Direct Lithium Extraction (DLE), are emerging as a promising solution and being tested at scale.

These technologies aim to efficiently extract lithium from lower-quality brine sources, achieving faster extraction (hours to days) and higher recovery rates (70%-90%+) than evaporation methods, while also reducing land footprint and potentially carbon intensity and freshwater usage.[10] [11] [12] This development is particularly relevant in Europe and North America, where efforts are underway to localise supply chains and reduce the industry's carbon footprint.

Despite the current low price environment and technical hurdles, investment in DLE technologies continues to grow, with BloombergNEF estimating global DLE capacities to exceed 500 kt LCE by 2030.[13] Globally, there are several projects already operating or under construction and more in planning, including:

- Qinghai Salt Lake Industry in China (operating at commercial scale);
- Citic Guoan in China (commercial scale);
- Arcadium Lithium in Argentina (blending DLE with evaporation ponds);
- Eramet and Tsingshan JV in Argentina (first production planned in November 2024);
- Vulcan Energy in Germany, planning to produce the world's first Zero Carbon Lithium (by 2026);
- Albemarle's expansion project in Chile (by 2028) and pilot plant project in projects in the US (under construction).

In addition to primary refined lithium, recycled lithium from spent EV and ESS batteries and production scrap will increasingly contribute to demand over the next decades. Globally, battery recycling could supply around 230 kt LCE of secondary material (8% of global supply) by 2030, nearly 9 times the levels of 2023 (27 kt LCE, or 3% of supply), according to Wood Mackenzie.[14]

3. The European lithium market

3.1 Demand from lithium-ion batteries

In Europe, the demand for lithium from lithium-ion batteries will be supported primarily by the uptake of EVs following the EU regulations on CO2 emission standards for light and heavy duty vehicles. Sales of new electric cars and vans are projected to hit 11.1 million units by 2030, while zero-emission commercial vehicles, powered by either batteries or fuel cells, are expected to reach 0.2 million units.[15]

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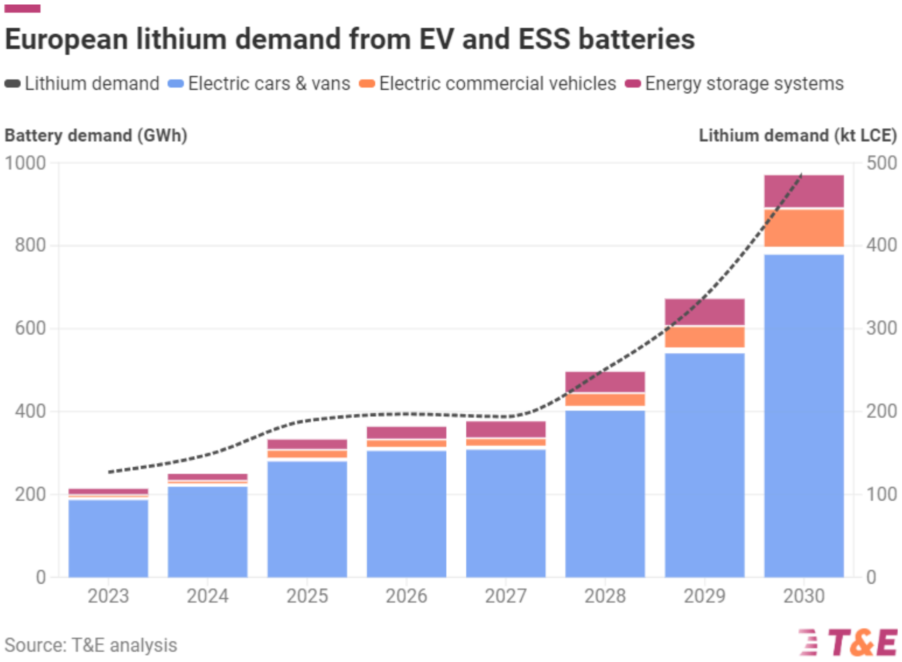
[10] McKinsey & Company. (12.04.2022). "Lithium mining: How new production technologies could fuel the global EV revolution". URL
[11] Goldman Sachs. (2023). "Direct Lithium Extraction: A potential game changing technology". URL
[12] BloombergNEF (13.05.2024), "Direct Lithium Extraction - Readiness assessment". URL
[13] BloombergNEF (13.05.2024), "Direct Lithium Extraction - Readiness assessment". URL
[14] Wood Mackenzie (28.06.2024). "Global electric vehicle & battery supply chain risked EV outlook - Q2 2024". URL
[15] Figures revised downwards compared to T&E's report "Paving the way to cleaner nickel".

This increase in electric vehicle adoption, along with the growing use of energy storage systems, is expected to drive battery demand to nearly 1 TWh and lithium demand to around 490 kt LCE by 2030, up from around 215 GWh and 130 kt LCE in 2023, respectively.[16]


European lithium demand from EV and ESS batteries

Source: T&E analysis

3.2 Trade flows

Europe is currently a net importer of lithium, with imports of lithium carbonate and hydroxide reaching their peak between 2020 and 2022 due to increasing demand from EV batteries. However, in 2023, imports dropped considerably by around a third year-on-year amid softening end use demand and cautious consumer behaviour.

Specifically, in 2023, the EU imported lithium carbonate mainly from Chile (70%) Argentina (10%) and the US (9%). Imports of lithium hydroxide were sourced from China (41%), Chile (22%), the US (15%) and Switzerland (13%).[17] At the same time, in 2023 the EU exported some small volumes of lithium products to the UK, Turkey, the US and South Korea.

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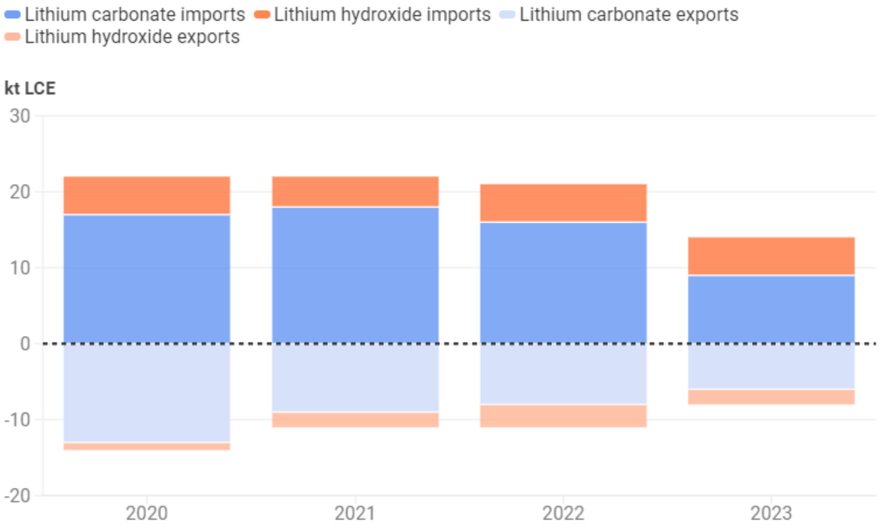
[16] This demand projection is based on T&E's Regulatory Scenario, which aligns with EU regulations on CO2 emissions standards for light and heavy-duty vehicles.

[17] In the EU, lithium hydroxide and lithium oxide are classified under the same HS code (282520). Historically, almost all trade under this code has involved lithium hydroxide. For the purpose of this analysis, it has been assumed that 98% of the volumes correspond to lithium hydroxide.

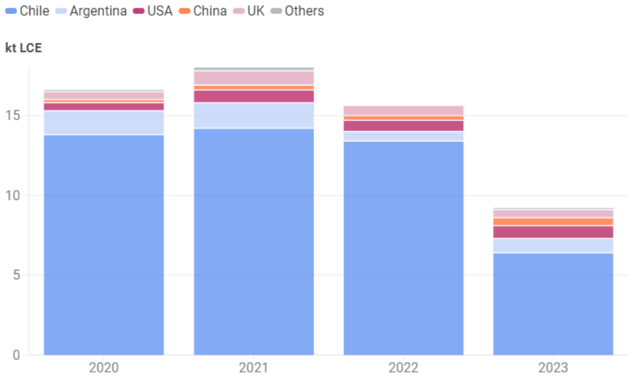
EU imports and exports of lithium



Source: T&E analysis of trade data from Access2Markets (European Commission) • HS codes 283691 (lithium carbonate), 282520 (lithium oxide and hydroxide)

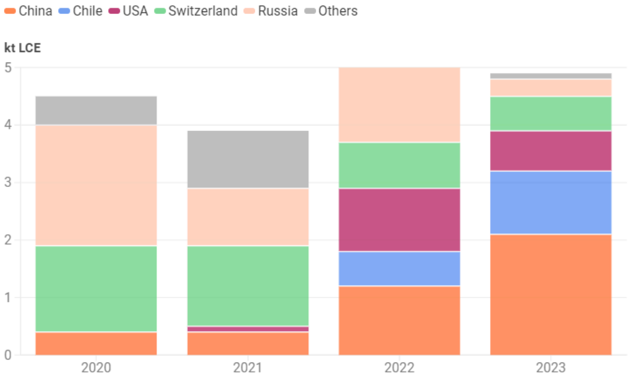
In recent years, the EU has changed its lithium import sources to adapt to shifting geopolitical and market conditions. Previously, Russia and Switzerland were the main suppliers of lithium hydroxide to the EU, but since 2022, the EU has increasingly relied on China, Chile and the US. This growing dependence on China, which dominates the battery value chain, and Chile, already the major supplier of lithium carbonate, highlights the urgent need for Europe to enhance its local manufacturing capabilities to better manage potential supply risks and import over-reliance.

EU imports of lithium carbonate



Source: T&E analysis of trade data from Access2Markets (European Commission) • HS code 283691 (lithium carbonate)

EU imports of lithium oxide & hydroxide



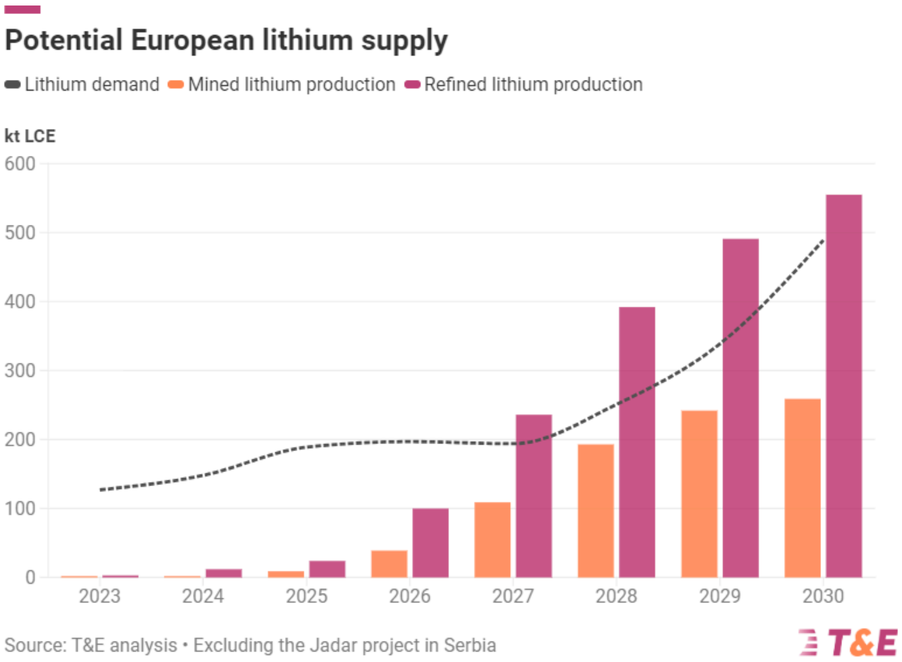
Source: T&E analysis of trade data from Access2Markets (European Commission) • HS code 282520 (lithium oxide and hydroxide)

3.3 Supply

While today Europe mines small amounts of lithium, primarily in Portugal for the ceramics industry, and imports the lithium required by the battery industry, the announced projects are expected to reduce this gap. According to T&E's latest count, the project pipeline includes 15 projects integrated with mining and refining, 2 mining projects and 11 stand-alone refining projects, involving both mineral and brine sources and located all across Europe.

By 2030, the mining capacity (from minerals and brines) is estimated to reach 310 kt LCE, with a potential production output of 250 kt LCE,[18] or around 53% of the projected European battery demand from EVs and ESS. Announced refining projects have a combined capacity of around 690 kt LCE,[19] potentially producing nearly 560 kt LCE in the form of lithium carbonate and hydroxide by 2030, which is theoretically sufficient to cover all of the region's future demand. The Jadar project in Serbia by Rio Tinto, not included in these figures, could add another 58 kt LCE to the European capacity. However, only a few projects are currently in advanced stages of development or more likely to proceed. Among these, AMG Lithium has just opened a refinery in Germany, while two integrated projects, Keliber in Finland and Cornish Lithium in the UK, are under construction and expected to start in 2025-2026. RockTech plans to start building its refinery in Germany in the last quarter of 2024.

It is also important to note that integrated projects have feedstock security, but take longer timelines and higher complexity to build, whereas stand-alone refineries are faster to build, but are reliant on third party feedstock availability. Therefore, the success of the European refineries will be dependent on the ability to secure reliable lithium sources in a fast moving market, amid growing global competition. African sources are secured by China, Australia is focused on vertical integration and Canada is emerging as the most viable option for European refineries.[20]



Source: T&E analysis • Excluding the Jadar project in Serbia

4. Environmental aspects

Lithium production can raise environmental challenges, particularly in GHG emissions and water use. Lithium extraction from brine deposits is generally less energy-intensive compared to hard rock mining, but uses large amounts of water, particularly in arid regions like the Atacama Desert, which can deplete

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[18] These estimates are indicative of potential. They assume a progressive ramp-up in production with a maximum utilisation rate of 85% across all announced projects. Actual outcomes may differ as projects evolve.

[19] Since the publication of T&E's report "An Industrial Blueprint for Batteries in Europe", T&E has added AMG Lithium's expansion plans in Germany to the pipeline.

[20] Fastmarkets (25.07.2023). "Will Europe have enough lithium to meet demand?". URL

local water resources. Conversely, hard rock mining, while often requiring less water, involves more extensive and energy-heavy processes resulting in higher GHG emissions.

4.1 GHG emissions

Lithium can be produced using various methods and from different deposits, resulting in a range of carbon intensities. The following LCA cradle-to-gate analysis by Minviro, commissioned by T&E, evaluates the emissions from producing lithium hydroxide monohydrate (lithium hydroxide in crystalline form) for nickel-based lithium-ion batteries, covering 6 distinct brine and hard rock operations, existing and prospective, located in Germany, Portugal, Australia and China and broadly 4 processes (and do not reflect production route averages).[21] These include:

DLE from geothermal brine (Germany): Rather than being evaporated, brine is extracted from deep geothermal reservoirs directly. The brine is processed using a Direct Lithium Sorption technology to produce lithium chloride, which is then converted to lithium hydroxide monohydrate through electrolysis and crystallisation. The DLE route in this analysis is based on a prospective operation in Germany.

Conventional brine (Chile): Lithium-rich brine is extracted from the Salar of Atacama and concentrated via solar evaporation to produce lithium chloride. This concentrate is purified, converted to lithium carbonate and ultimately to lithium hydroxide monohydrate via electrolysis and crystallisation, using various reagents along the way. In the present analysis, an operation located in Chile was assessed.

Spodumene (Portugal and Australia): Spodumene ore is upgraded to spodumene concentrate, which undergoes pyrometallurgical treatment, followed by hydrometallurgical processing such as leaching with sulfuric acid, chemical purification, conversion to lithium hydroxide monohydrate and final crystallisation. The Australian route (of an existing operation) involves the transport of spodumene concentrate to China for further processing, while the Portuguese process (prospective operation) handles conversion within Portugal.

Mica (Germany and China): Mica ore, which represents lower-grade lithium-bearing ore such as lepidolite (processed in China, current operation) and zinnwaldite (processed in Germany, future operation) is upgraded to a concentrate. This concentrate undergoes roasting, followed by leaching into lithium sulphate and conversion into lithium hydroxide monohydrate through chemical processing and crystallisation. In China, the lithium sulphate undergoes an extra step of conversion into lithium carbonate before being converted into lithium hydroxide. The processing of mica ore requires reagents both in the pyrometallurgical and hydrometallurgical steps, each with its own embodied emissions.

A comparison of GHG emissions from various lithium production routes reveals significant variation in emissions depending on the lithium source, energy inputs and chemical processes involved.

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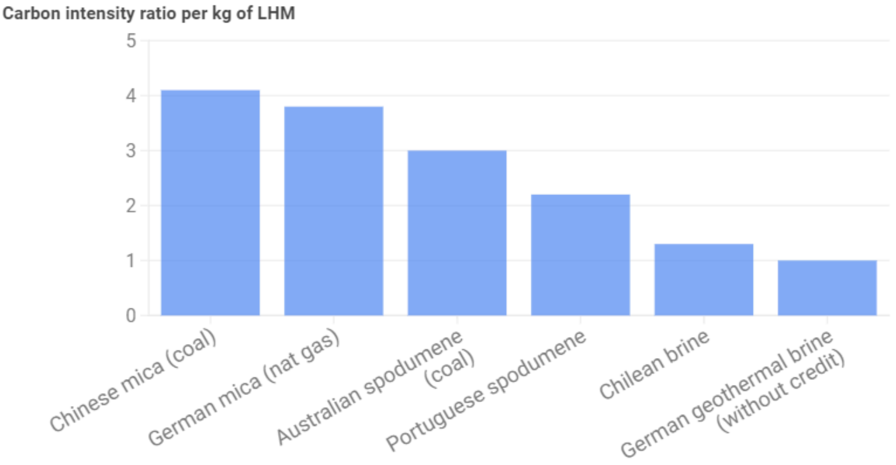
[21] Results are presented in the charts below as a ratio of lowest climate change impact route. Publicly available data was included in a separate chart in the Appendix section.



GHG emissions from lithium hydroxide monohydrate production

Source: Minviro • Note: LHM refers to lithium hydroxide monohydrate ($LiOH \cdot H_2O$). Results are presented as a ratio of lowest climate change impact route. The Australian spodumene route includes mining in Australia and refining in China.

Brine-based production, whether conventional or DLE, shows the lowest emissions. The reliance on natural processes like solar evaporation in Chile and the use of geothermal energy in Germany provide an important advantage in reducing carbon emissions. German geothermal DLE extraction, in particular, has minimal emissions as it benefits from using naturally heated brine as a primary source of energy and employs electrochemical processes with low reagent consumption. As a result, this route generates 83% fewer emissions than the most carbon-intensive route, Chinese mica, and 77% fewer than the typical Australian spodumene route.

Lithium extraction from Australian and Portuguese spodumene have higher emissions than brine-based due to the complex, energy-intensive pyrometallurgical processes that use fossil fuels for mineral conversion and steam production, as well as due to the consumption of reagents such as sulphuric acid. Nonetheless, excluding brine sources, lithium production from European spodumene generates fewer emissions than from Australian spodumene, owing to a better energy mix (which includes Portuguese grid and natural gas). If the Portuguese operation switched to fully renewables-based electricity as part of its energy mix, emissions could be reduced by 8%. For this operation alone, this could provide savings of nearly 25 kt of CO2 equivalent annually, compared to the current energy mix.[22] For further emission reduction, the company would need to electrify energy-intensive processes and power them with renewables.

On the other end of the spectrum, lithium production from Chinese mica is the most carbon-intensive, generating over 4 times more emissions than German geothermal brine and twice as much as the Portuguese spodumene route with renewable energy. The high emissions are attributed to the lower grade ore, energy-intensive processes reliant on coal and natural gas as well as high usage of reagents in both pyrometallurgical and hydrometallurgical steps.

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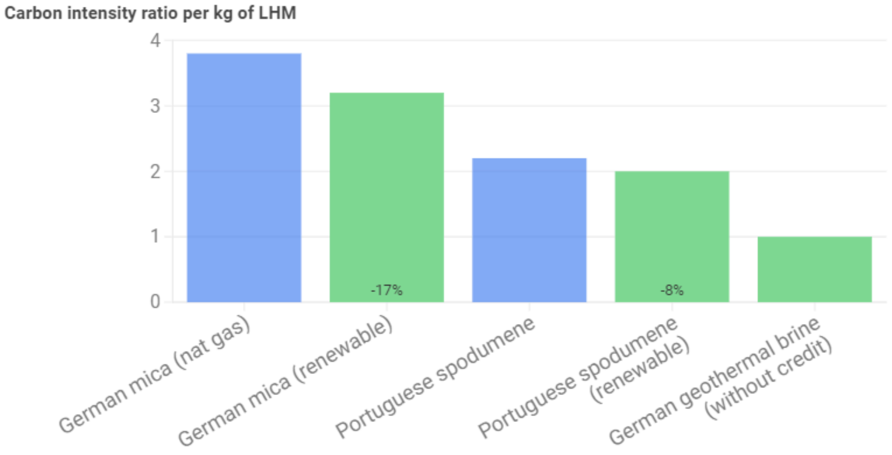
[22] Estimate based on a plant with a capacity of 32 kt lithium hydroxide monohydrate (or 28 kt LCE) operating at 85% capacity utilisation.

While not ideal, the German mica production is more favourable than the Chinese mica route, especially when combined with renewable energy, potentially reducing emissions by up to 17%.

Apart from renewables and DLE, other innovations to reduce GHG emissions lie in processes themselves, notably increasing process efficiency and using lower-emission reagents.

GHG emissions savings from lithium hydroxide monohydrate production in renewable scenarios



Source: Minviro • Note: LHM refers to lithium hydroxide monohydrate ($LiOH \cdot H_2O$). Results are presented as a ratio of lowest climate change impact route.

All in all, the following measures can help reduce GHG emissions from lithium extraction:

Technology: DLE, when applied to geothermal brines, significantly reduces GHG emissions by utilising geothermal energy for power and heat, avoiding mining and fossil fuel inputs. Lithium production from geothermal brine generates 77% fewer emissions than the prevailing Australian spodumene route.

Renewable energy: Maximising renewables in the electricity mix in operations processing lithium from hard rock sources can also reduce emissions by up to 17%, or almost a fifth, as shown in the LCA analysis.

Process efficiency: Reducing steps to eliminate heat-intensive processes such as beneficiation, calcination and roasting or, alternatively, electrifying these processes and using renewable energy can reduce emissions. For example, Infinity Lithium in Spain adopted a production flowsheet that eliminates traditional chemical conversion operations from hard rock sources, such as the beneficiation, calcination and roasting, by relying solely on hydrometallurgical processes like leaching, purification and crystallisation (via the patented Li-Stream RPK process).[23]

European Metals at their Cinovec project in the Czech Republic simplified the precipitation/crystallisation processes by reducing the number of steps and equipment for purification, including the elimination of energy-intensive cooling processes.[24]

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[23] Global Mining Review. (12.09.2023). "Infinity successfully produces battery grade lithium hydroxide". URL

[24] European Metals. (31.10.2022). "Simplified Extraction Process Delivers Exceptionally Clean Battery-Grade Lithium Product With Improved Economics". URL

The JV of Northvolt and Galp in Portugal, Aurora, will implement a phased approach to decarbonizing their calciner operations. They will start by incorporating green hydrogen into the calciner's energy mix, and then electrify the calcination stage using renewable energy.

Lower-carbon reagents: Considering that reagents used during lithium production can have significant embodied emissions, operations could minimise the use of carbon-intensive reagents in favour of those produced with renewables or by implementing on-site recycling systems. In Europe, companies like Vulcan Energy in Germany,[25] European Metals in the Czech Republic[26] and Infinity Lithium in Spain[27] plan to recycle reagents in their operations.

4.2 Water use

The traditional lithium extraction processes involve water usage, with a large share of lithium production being located in water-stressed regions.[28] As demand for lithium increases, more efficient and better water saving technologies and practices become ever more important.

In brine operations, water undergoes evaporation as the brine is concentrated. Water is also used for washing lithium trapped in the precipitated salts and for preparing reagent solutions. In lithium extraction from hard rock, water is primarily employed for reagents, and also in filtration and flotation processes, cooling processes and for washing the final lithium product.[29]

The following life cycle assessment (LCA), conducted by Minviro and commissioned by T&E, evaluates water impacts across several lithium production routes using the AWARE methodology (Available WAter REmaining), as recommended by UNEP. This approach measures consumptive water use, or water withdrawn and not returned to the watershed, while considering the remaining available water per area after meeting human and ecological needs (in other words, the potential of an operation to deprive other users of freshwater). It is important to note that consumptive water use reflects the potential of an operation to deprive other users of water, rather than just the project's actual water consumption.

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[25] Vulcan Energy. (2024). “Annual Report 2023”. URL

[26] European Metals. (April 2023). “Ethically-sourced European battery metals to power Europe's sustainable future.” URL

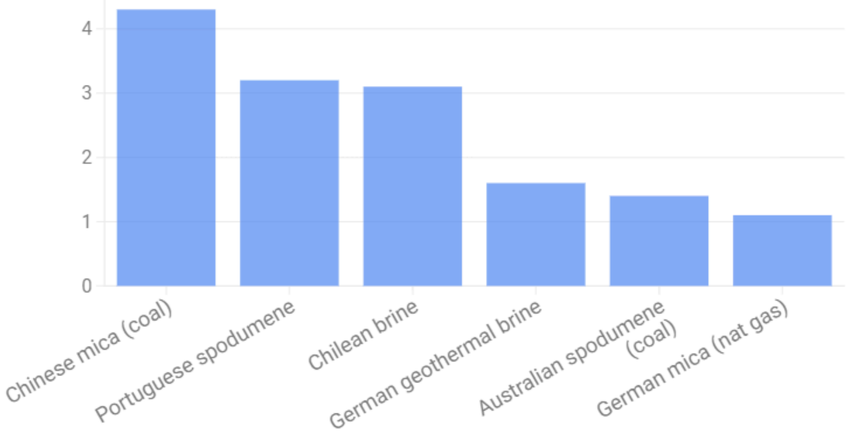
[27] Infinity Lithium. (07.04.2022). “Accelerating Europe's Drive Towards Energy Independence.” URL

[28] According to IEA, around half the lithium production in 2021 was concentrated in areas with high water stress levels. Source: IEA (05.2021, revised 03.2022). “The Role of Critical Minerals in Clean Energy Transitions”. URL

[29] BloombergNEF. (17.09.2019). “Advancing Water Efficiency in Lithium Extraction”. URL

Water use in lithium hydroxide monohydrate production

Water intensity ratio per kg LHM



Source: Minviro • Note: LHM refers to lithium hydroxide monohydrate ($LiOH{\cdot}H_2O$). Results are presented as a ratio of lowest climate change impact route. The Australian spodumene route includes mining in Australia and refining in China.

In Germany, the lithium production from mica stands out with the lowest water use impact, attributed to the country's favourable water scarcity factor (1.8 m3 eq/m3) and relatively low direct water use in the process (although it fares relatively high in emissions). The geothermal route also has a relatively low water footprint, being 50% lower than the Chilean brine route.

The Australian spodumene route has a comparatively low water footprint due to reduced usage of sulfuric acid and lower water scarcity factors both in Australia (14.9 m^3 world eq/m^3) and China (0.2 m^3 world eq/m^3), where the mining and refining occurs, respectively. Conversely, Portugal's relatively high water use impact is driven by its significant water scarcity factor (24.4 m^3 world eq/m^3) and higher usage of sulfuric acid in processes.

The Chilean brine route, while low in GHG emissions, scores relatively high in water use. Chile, particularly the Salar de Atacama region, has a very high water scarcity factor (94.7 m^3 world eq/m^3). This is exacerbated by the fact that the water extracted from the aquifers is not returned but evaporated.

Although China has low water stress (0.2 m^3 world eq/m^3), its lithium production from mica has the highest water use among the routes analysed, being 4 times higher than the German mica route and nearly 3 times higher than the DLE route. This high water footprint results from the large quantities of sulfuric acid required for processing as well as the high water demand associated with the production of fossil fuel-based energy (i.e. for cooling processes in power plants).

As this LCA water analysis shows, the water footprint of an operation is influenced by the regional water scarcity, the energy requirements and sources and demand for water-intensive reagents like sulfuric acid. European lithium production is noted for its relatively low water use potential, particularly for lithium from mica sources and DLE from geothermal brines.

Looking at the innovations happening in the industry, a number of technologies and best practices are being developed and adopted to improve the water performance of lithium extraction and processing.

Direct Lithium Extraction (DLE): DLE technologies improve water efficiency due to their high selectivity in extracting lithium ions directly from brine, resulting in better recovery rates. Unlike traditional methods that rely on evaporation ponds to concentrate lithium, DLE processes streamline production by minimising the volume of brine needed and eliminating the evaporation phase. In recent years, various DLE techniques have emerged, some initially developed for desalination and wastewater treatment. For example, adsorption is the most advanced DLE technology and can cut water by 30%-60%, according to BloombergNEF.[30] In Europe, Vulcan Energy in Germany is applying this technology to geothermal brines. Other DLE technologies like ion-exchange or membrane filtration (e.g. nanofiltration, reverse osmosis) can achieve even greater water efficiency, reducing water intensity by 60%-100% compared to the conventional brine route, though they are still in early stages of development.

In mineral extraction, ion-exchange is considered the most water efficient technology for purifying lithium solutions after the leaching process. For example, Nemaska Lithium in Canada[31] and possibly Zinnwald Lithium in Germany plan to utilise ion exchange alongside other technologies at their conversion (refining) facilities.[32]

Water recovery and recycling: Implementing water recycling technologies, including water recirculation systems (where the water is continuously cycled through the system), can further reduce water consumption and mitigate water scarcity in water-stressed regions. It appears that reverse osmosis, which involves pumping water at high pressure through membranes to remove salts and impurities, is a widely adopted water purification technology across industries due to its effectiveness in removing a broad range of impurities. In lithium extraction, reverse osmosis can be utilised for water treatment and recovery. Specifically in brine extraction, it is used as a complementary technology for pre-treating or post-treating brine (to concentrate lithium), while at the same time recovering water. Furthermore, ongoing research is exploring the potential of reverse osmosis as a standalone DLE technology.

For example, Imerys plans to recycle 90% of the water used at its EMILI project in France, employing water recirculation systems in both the concentration and the chemical conversion stages. The conversion plant will source water from a nearby wastewater treatment plant and deploy reverse osmosis to treat it for its processes.[33] In Argentina, French mining company Eramet has recently commissioned a DLE plant that intends to recycle 60% of its water by reverse osmosis and forced evaporation (i.e. using external energy sources), which will allow for lithium concentration and water recovery. [34]

In hard rock mining, tailings dewatering (or drying) supports water recycling by extracting water from the slurry of crushed rock and waste materials left over from ore processing. This recovered water can be reused in the production process, reducing the need for freshwater inputs. The dewatering process also results in a more manageable solid byproduct and minimises dam requirement and the risks associated with dam failures.[35] Dry stacking of filtered (or dewatered) tailings stored in dry stacks or backfilled as

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[30] BloombergNEF. (17.09.2019). "Advancing Water Efficiency in Lithium Extraction". URL

[31] BloombergNEF. (17.09.2019). "Advancing Water Efficiency in Lithium Extraction". URL

[32] Zinnwald Lithium. (06.09.2022). "Preliminary Economic Assessment for the revised Zinnwald Lithium Project". URL

[33] Imerys. (March 2024). "IMERYS projet EMILI. Débat public dossier du maître d'ouvrage". URL

[34] Eramet. (March 2023). "Eramet in Argentina Centenario-Ratones Lithium Project". URL

[35] Cacciuttolo C., et al. (16.11.2023). "Dry Stacking of Filtered Tailings for Large-Scale Production Rates over 100,000 Metric Tons per Day: Envisioning the Sustainable Future of Mine Tailings Storage Facilities", *Minerals*, 13(11). URL

paste underground is expected to be adopted by multiple European emerging players, including Imerys in France,[36] European Metals in the Czech Republic,[37] Infinity Lithium in Spain[38] and Savannah in Portugal.[39]

Zero Liquid Discharge (ZLD): Zero Liquid Discharge is an advanced water management approach that ensures all process water is fully recycled and reused, creating a closed-loop system with no liquid waste discharge. This method recovers all process water and converts contaminants into solid waste. ZLD systems often combine technologies like reverse osmosis or electrodialysis reversal (to remove dissolved solids), thermal technologies like evaporators (to concentrate brine and recover pure water) and crystallizers (to produce solids for disposal or reuse).[40] One of the companies planning to integrate this approach is Lithium Americas at Thacker Pass in the US.[41]

Water reinjection: In DLE brine extraction, particularly in arid areas, water reinjection can help maintain local hydrology. After lithium extraction, the remaining spent brine can be reinjected into the aquifer from which it was drawn to preserve groundwater levels and minimise net water loss from the ecosystem. However, reinjection has to be managed carefully, with the brine properly treated, and constantly monitored to prevent contamination and aquifer damage.[42] [43] In Germany, Vulcan Energy plans to use a closed loop water cycle that integrates geothermal heat transfer, lithium extraction and brine reinjection back into the geothermal reservoir, while Eramet is planning direct reinjection into the salt flats at its operation in Argentina.

Desalination. In areas where freshwater is scarce, desalination has become an increasingly important technology for providing water to lithium operations. Desalination plants convert seawater into fresh water that can be used in the lithium extraction and processing stages, thus reducing the reliance on local freshwater sources. For example, in 2019, desalinated seawater accounted for 20% of water use in Chile's mining industry, primarily for copper production.[44] Major lithium miners there are also investing in desalination to support their operations.[45]

Nonetheless, some of the environmental challenges associated with the process include its high energy requirement and the generation of waste (i.e. the resulting concentrated brine and chemical residues from the pretreatment stages). Desalination can be done via electrically driven technologies, most commonly via reverse osmosis and electrodialysis, which uses electricity to move ions through membranes to separate salt from water. Alternatively, it can be done via thermally driven technologies such as distillation, which involves boiling water and collecting the vapours, but thermal desalination technologies generally require substantial energy inputs (as well as higher maintenance costs).[46]

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[36] Imerys. "Management of waste rock and tailings: a factor taken into consideration from the outset of the project". URL

[37] Liberum (25.01.2024). "European Metals - Initiation. 'Best in class' Cinovec - key to lithium supply independence for Europe". URL

[38] Infinity Lithium. (19.06.2024). "Infinity to present at the 2024 RIU Gold Coast Investment Showcase". URL

[39] Savannah. (March 2023). "Barroso Lithium Project - COmmunity Information Sheet". URL

[40] Saltworks Technologies. (2018). "What is Zero Liquid Discharge?" URL

[41] Lithium Americas. (14.12.2023). "Recycling and Reusing Process Water to Minimize Environmental Impacts". URL

[42] Walter S., et al. (June 2024). "A preliminary assessment of reinjection of direct lithium extraction effluent-based miscible fluids in unconfined salar aquifers". URL

[43] International Lithium Association. (June 2024). "Direct Lithium Extraction (DLE): An Introduction". URL

[44] Fluence. "Desalination in Mining". URL

[45] S&P Global. (17.01.2023). "Chilean lithium miners to use desalinated water to quell water use concerns". URL

[46] Climate ADAPT. (03.09.2016). "Desalinisation". URL

One way to reduce the carbon footprint of desalination processes is pairing lower energy technologies like reverse osmosis with renewable energy sources. According to a review of GHG emissions from desalination systems, reverse osmosis technologies powered by solar or wind energy emit significantly fewer emissions (0.4 - 2.3 kg CO2 eq./cubic metre) than thermal technologies (up to 34.7 CO2 eq./cubic metre for multi-stage flash distillation), but still generally higher than emissions from water reuse systems (0.1 - 2.4 kg CO2 eq./cubic metre).[47]

To address the waste generation issue associated with desalination, companies can convert the waste brine, which is usually discharged into the sea, into useful chemicals, such as sodium hydroxide and hydrochloric acid. These chemicals can be reused in the desalination plant and have other industrial uses.[48]

Overall, desalination in mining operations should be carefully considered, but could be an option if they are co-located in coastal areas of arid regions and provided that the desalination plant employs less energy-intensive technologies combined with renewables (solar, wind, wave and tidal) and waste valorization practices.

5. Conclusions and policy recommendations

Among battery metals, Europe has the highest potential for local lithium production, with 28 mining, refining and integrated projects in the pipeline. However, lithium production also comes with environmental and social impacts and trade-offs, and companies must carefully choose the most sustainable methods, while adopting the best available technologies and practices.

To unlock Europe's potential sustainably and responsibly, robust political, policy and financial support will be essential.

1. As part of its Critical Raw Materials Act, the European Commission should support the development of domestic lithium production capacities by backing Strategic Projects - in particular those focused on refining, recycling and tailings reprocessing - that are innovative and adhere to strong environmental and social standards. This support should include:
    a. Rewarding innovative lithium technologies such as Direct Lithium Extraction;
    b. Supporting projects that implement energy-efficient processes and achieve low GHG emissions, such as reducing heat-intensive process steps or electrifying processes with renewables.
    c. Rewarding projects that implement best practices related to:
        i. Water management: Implementing water recovery and recycling technologies, closed loop water systems and tailings dewatering techniques as well as adopting Zero Liquid Discharge approach;
        ii. Waste management: Employing tailings dewatering, dry stacking and backfilling techniques.

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[47] Pablo K. Cornejo, et al. April 2014. "Carbon footprint of water reuse and desalination: a review of greenhouse gas emissions and estimation tools". URL

[48] Massachusetts Institute of Technology News. (13.02.2019). "Turning desalination waste into a useful resource". URL

        iii. Biodiversity: Adhering to the mitigation hierarchy of avoiding, minimising, restoring and offsetting negative impacts on biodiversity; implementing habitat restoration and reforestation programs throughout the life cycle of the mine and at least no net biodiversity loss by 2030.
        iv. Human rights and indigenous people: Implementing OECD/UNGP human rights due diligence guidelines, ILO labour conventions and strong policies on fair wages, corruption and gender and minority rights as well as committing to the principles of the UN declaration on Free, Prior and Informed Consent (FPIC).
    d. Supporting projects with multi-stakeholder governance, independent third-party audits and transparent disclosure, particularly those that have undergone or are undergoing an audit by the Initiative for Responsible Mining Assurance (IRMA).

2. The European Commission, EU governments and businesses should accelerate investment into the research, development and commercial scaling of energy-efficient, water-saving technologies, which can also be exported globally. More broadly, to support sufficient scaling of sustainable and diverse lithium supply, the EU should join forces with like-minded partners such as the US and provide financial support for high ESG projects. This can take the form of price support, contracts for difference (CfDs), green premiums or other similar tools. This should also include robust low carbon and sustainability standards in global trade and climate deals to reward cleaner extraction and production methods.

3. As part of the EU taxonomy for sustainable activities, the European Commission should define “low emission” lithium and set thresholds to attract private capital into scaling clean tech. T&E recommends a threshold of 10 kg CO_2e/kg lithium hydroxide monohydrate by 2030.

Further information

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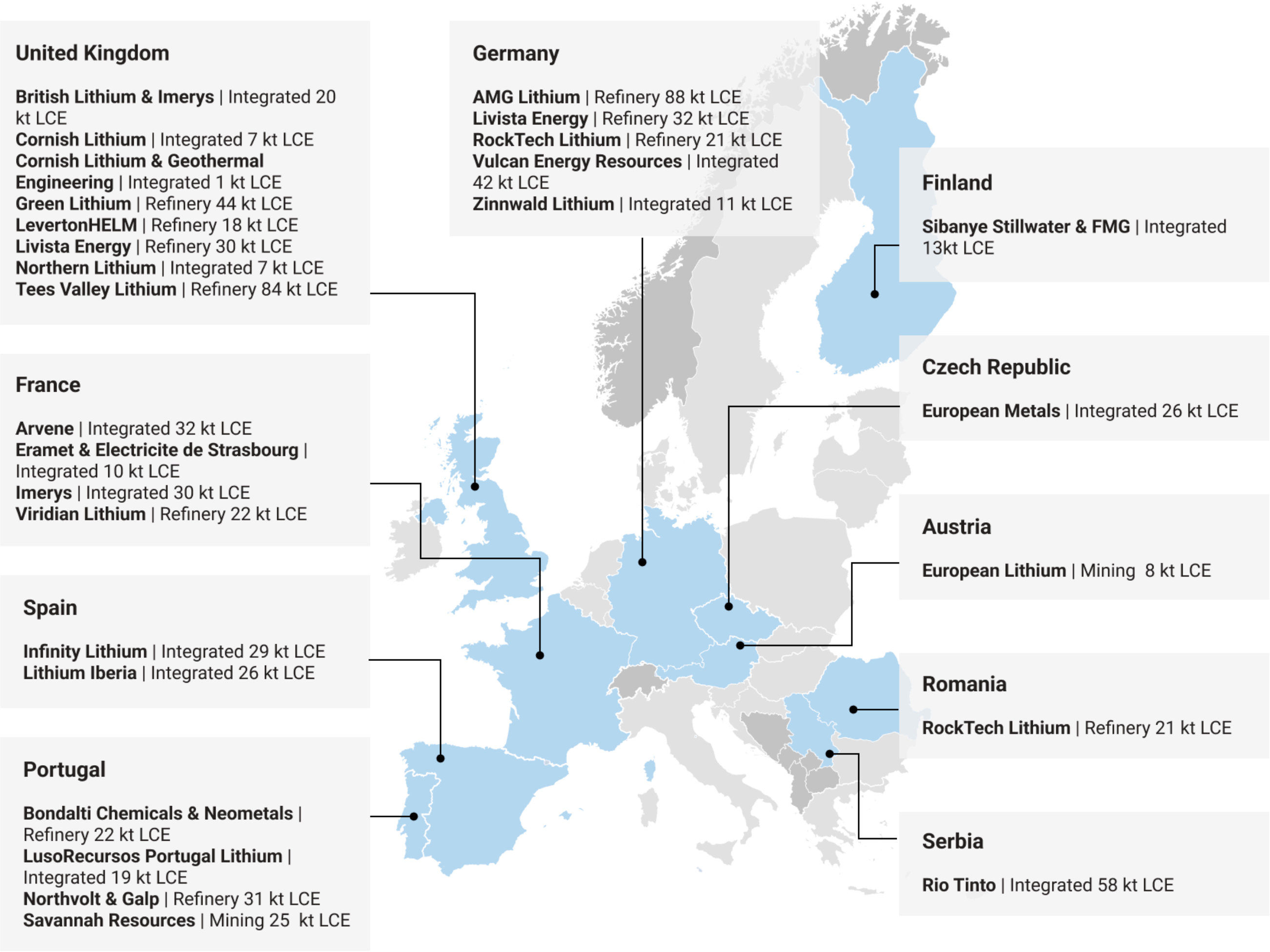
Appendix

Upcoming lithium projects in Europe by 2030

Upcoming Lithium Projects in Europe by 2030

Mined capacity: 363 kt LCE - **Refined capacity:** 742 kt LCE



United Kingdom

British Lithium & Imerys | Integrated 20 kt LCE
Cornish Lithium | Integrated 7 kt LCE
Cornish Lithium & Geothermal Engineering | Integrated 1 kt LCE
Green Lithium | Refinery 44 kt LCE
LevertonHELM | Refinery 18 kt LCE
Livista Energy | Refinery 30 kt LCE
Northern Lithium | Integrated 7 kt LCE
Tees Valley Lithium | Refinery 84 kt LCE

Germany

AMG Lithium | Refinery 88 kt LCE
Livista Energy | Refinery 32 kt LCE
RockTech Lithium | Refinery 21 kt LCE
Vulcan Energy Resources | Integrated 42 kt LCE
Zinnwald Lithium | Integrated 11 kt LCE

France

Arvene | Integrated 32 kt LCE
Eramet & Electricite de Strasbourg | Integrated 10 kt LCE
Imerys | Integrated 30 kt LCE
Viridian Lithium | Refinery 22 kt LCE

Spain

Infinity Lithium | Integrated 29 kt LCE
Lithium Iberia | Integrated 26 kt LCE

Portugal

Bondalti Chemicals & Neometals | Refinery 22 kt LCE
LusoRecursos Portugal Lithium | Integrated 19 kt LCE
Northvolt & Galp | Refinery 31 kt LCE
Savannah Resources | Mining 25 kt LCE

Finland

Sibanye Stillwater & FMG | Integrated 13kt LCE

Czech Republic

European Metals | Integrated 26 kt LCE

Austria

European Lithium | Mining 8 kt LCE

Romania

RockTech Lithium | Refinery 21 kt LCE

Serbia

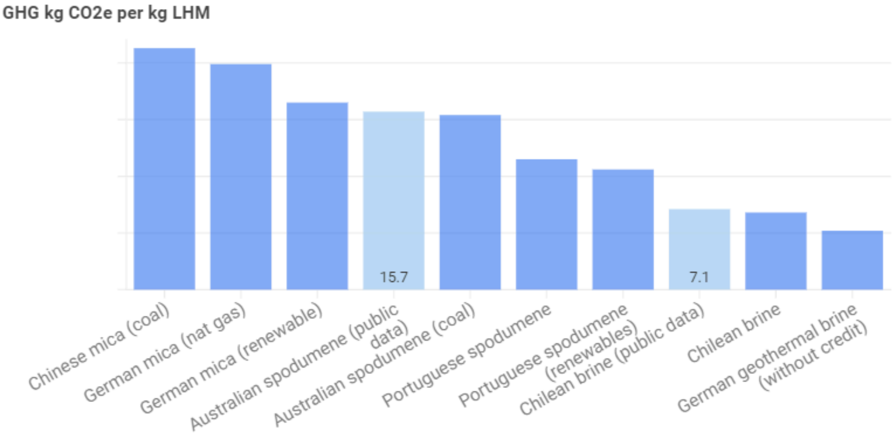
Rio Tinto | Integrated 58 kt LCE

Source: T&E monitoring of public announcements of projects. Figures exclude current operations and include the Rio Tinto project in Serbia.

GHG emissions from lithium hydroxide monohydrate production

The chart includes data from Minviro analysis along with publicly available sources,

GHG emissions from lithium hydroxide monohydrate production



Sources: (1) Minviro (2) Kelly, J. C., Wang, M., Dai, Q., Winjobi, O. 2021. Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium ion battery cathodes and lithium ion batteries. Argonne National Laboratory. • Notes: LHM refers to lithium hydroxide monohydrate (LiOH·H2O). The Australian spodumene route includes mining in Australia and refining in China.