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The Investment Landscape in the Lithium Triangle: Implications for the EU's Critical Raw Materials Act Agenda

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Abstract

This paper explores the role of the Lithium Triangle—comprising Argentina, Bolivia, and Chile—in the global supply of lithium, a critical raw material for the energy transition, including for the European Union (EU). Understanding the investment landscape in the Lithium Triangle is vital for the EU's ambitious green agenda. The paper provides an overview of how the production capacity of the Lithium Triangle is meeting the growing global demand. It analyses the regulatory frameworks, market dynamics, investment drivers, and bottlenecks. Additionally, it examines how this landscape aligns with the EU's ambitions to secure access to lithium. The findings indicate that, while the region holds significant potential to support the EU's green transition, the EU's marginal involvement as an active investor potentially risks future access. Further risks stem from growing firm concentration, environmental concerns, and regulatory uncertainties.

Keywords: Energy Transition, Mining, Lithium, Investment, Critical Raw Materials Act

JEL classification: F21, L70, O13, Q40

Note

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Introduction

The aim of rapid decarbonisation has some countries scrambling to secure the necessary supply of critical minerals, mostly metals. The problem is simple: at least in the short term, there is a shortage of some, like lithium. Shortages are expected to increase prices and, to some extent, solve the problem by boosting production as well as fostering innovative solutions that can help alleviate the supply crunch. At the same time, however, skyrocketing prices may result in unmet demand, jeopardising the goal of reaching net zero by 2050.

Though the problem is simple, the solution is not. First, scaling up mineral production takes years, sometimes decades. Second, metal prices, like other commodities, are highly volatile, making investment risky. Third, their production and processing are geographically concentrated, making them subject to geopolitical risk. Fourth, the mining industry faces an increasingly impoverished license to operate due to cases of violations of Environmental, Social, and Governance (ESG) standards, as well as widespread misconceptions about its practices. In other words, increasing supply, particularly in a genuinely sustainable manner, is a matter of having many conditions in place that are individually challenging to accomplish for countries, industries, and firms.

Lithium is one of the metals in question. Its market size is small compared to other metals like copper—nearly 40 billion compared to almost 200 billion in 2022 (International Energy Agency, 2023). However, its importance is difficult to overestimate. Lithium is present in Li-ion batteries, now massively used in Electric Vehicles (EVs) and, increasingly, in energy storage, necessary to deal with the intermittency of wind and solar sources (Temple-West, 2023).

Even though lithium is not scarce—global reserves increased by 30% between 2011 and 2019 while production increased two and a half times (IEA, 2022), it is highly concentrated. Latin America's "Lithium Triangle"—Argentina, Bolivia, and Chile—occupies a crucial position in the global lithium supply chain. Chile and Argentina are currently among the top four producers of primary materials with 30% and 5% of global production, respectively. Moreover, Chile and Bolivia are first and second among the holders of reserves worldwide—Chile 25% and Bolivia 45% (European Commission, 2023). While there are efforts by different governments to reduce the geographical concentration of critical minerals, most mineral output growth, except for copper, is expected to come from today's major producers (International Energy Agency, 2022).

The aim of this paper is twofold. First, we shed light into the mining industry as an essential factor that must be accounted for in the energy transition debate. Environmentalists, activists, politicians, and academics, at least in the way they publicly address the debate on energy transition,

often disregard that the mining industry is where the transition to renewable energy *begins*—there is no transition without metals. Widespread discussions of "green investments", have often suggested that bottlenecks are financial and a matter of political will. For instance, Sachs et al. (2019) argue that "[…] We need to scale up the financing of investments that provide environmental benefits if we want to achieve the SDGs, through new financial instruments and new policies, such as green bonds, green banks, carbon market instruments, fiscal policy, green central banking, "fintech", community-based green funds, etc., collectively known as "green finance" (Sachs et al., 2019, p. 1). They add that the three challenges faced by this solution are identifying the right projects, developing private-public plans for them, and structuring the financing. However, ignoring that there are *physical* constraints to substantially increase the required supply of minerals while *simultaneously being ESG-compliant*, risks a coherent and just energy transition. Therefore, we also describe the lithium landscape and highlight the crucial place the Lithium Triangle has in this landscape. We find that, while the region has the potential to play a pivotal role in the global supply of lithium, it also faces significant sources of vulnerability.

Second, we analyse the supply risk of lithium from the perspective of the European Union, a region with an utterly ambitious green agenda but lacking the necessary raw materials to achieve it. Unlike other advanced economies such as the US, Australia, or Canada, the EU heavily relies on third countries to secure its supply of raw materials—lithium is no exception. Therefore, understanding the potential investment landscape in the Lithium Triangle is particularly relevant to the EU. Based on this, we highlight the various drivers and bottlenecks for investment that the lithium industry in the Lithium Triangle faces.

The paper is organised as follows. First, we provide an overview of the EU context with respect to its raw materials needs and policy. Second, we offer an overview of lithium in relation to its current and estimated future supply and demand. Third, we present an overview of key investment domains. Fourth, we introduce the drivers and bottlenecks of investment in the Lithium Triangle. In the final section, we discuss the opportunities the Lithium Triangle represents for satisfying the EU's lithium demand.

I.) The EU and its need for raw materials

According to the estimates for EVs and energy storage in the foresight report of 2020 of the European Commission, which provides the outlook for 2030 and 2050 of critical raw materials, "the EU would need up to 18 times more lithium in 2030, and almost 60 times more lithium in 2050, compared to the current supply to the whole EU economy" (European Commission, 2020). In addition to the massive increase in demand, the EU is almost exclusively dependent on third countries for its sourcing: it imports between 75% and 100% of most metals used in its industries. With respect to lithium, demand in Europe for lithium compounds has been estimated to grow to 425,000 tons by 2030, while only between 100,000 and 150,000 can be produced domestically (DERA, 2023). Thus, a gap of about 300,000 tons of lithium chemicals needs to be filled and inevitably requires Europe to search for alternative suppliers.

Is Europe a poor continent resource-wise? At its peak in the 1850s, more than 60% of global mining output was extracted in Europe. Since then, the mining industry in the region slowly decreased and by the year 2000 only about 6% was located in Europe (Urzúa, 2013). The causes of this decline are beyond the scope of this paper, but this fact is sufficient to highlight two aspects. First, mining relocated elsewhere and brought about other players. In the first half of the 20th century, the leading position in mining was taken by the USA, after which new mining regions emerged; first Australia and Canada and later Latin America and Asia. In the 21st century, around 80% of (metallic) mining production takes place in 12 countries and the remaining 20% is produced in around 90 countries (Urzúa, 2013). Thus, while mining regions have changed, mining activities continue to be highly concentrated.

Second, while Europe has succeeded in outsourcing its mineral demand, this dependency on third countries has come with costs. For instance, many jurisdictions do not have adequate institutional frameworks that allow expedient issuing of permits. Likewise, the knowhow related to the management and operation of mines has petered out, creating a large skills gap in comparison to other advanced economies such as the US, Canada, and Australia or emerging China[1].

Prompted by the acute supply chain problems caused by the Covid-19 pandemic and the consequences of the Russian invasion of Ukraine for gas imports, the EU is seeking to diminish its dependence on raw materials from third countries. The Critical Raw Materials Act (CRMA), presented recently by the European Commission, tries to address the imbalance by setting "clear

[1] Darling (2011) suggests that there has been a permanent loss of knowledge across the industry, pointing out the disappearance of undergraduate programmes in renowned institutions. However, this is particularly acute in Europe.

benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030" (European Commission Joint Research Centre, 2023). Specifically,

i) at least 10% of the EU's annual consumption should be domestically extracted;

ii) at least 40% of the EU's annual consumption should be domestically processed;

iii) at least 15% of the EU's annual consumption should be recycled; and

iv) not more than 65 % of the Union's annual consumption of each strategic raw material at any relevant stage of processing should come from a single third country.

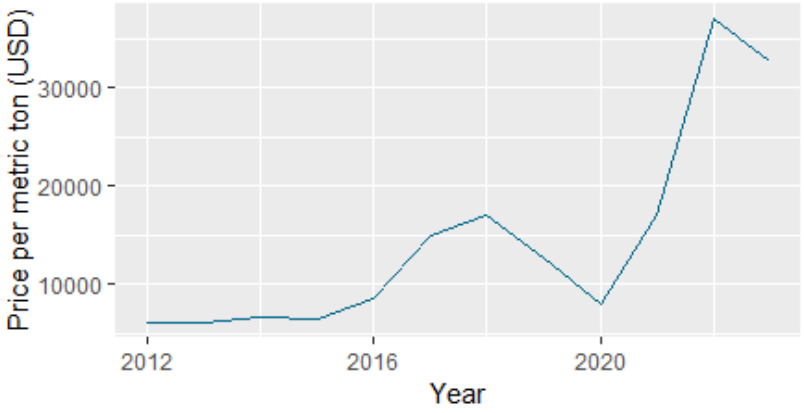
While this policy proposal is comprehensive, it does not sufficiently acknowledge the challenges *within* the mining industry. As stated by Nicola Beer, (vice-president, Germany, Renew Europe) at the European Parliament, the CRMA is an effective piece of legislation for the signals it sends to markets of what is needed. It offers guidance as to regulatory frameworks and may facilitate partnerships such as the Mining Security Partnership. However, it is by itself insufficient to overcome the difficulties in establishing a domestic industry and resilient supply chains. For instance, the EU import reliance for processed/refined lithium, calculated as the ratio of net imports to apparent consumption is 100% (European Commission, 2023). Likewise, in 2022, the EU imported 85% of its refined lithium carbonate from Chile. The second supplier was the United States, with 4.4% (World Bank, 2023). Ramping up its own supply or deconcentrating its supply cannot be achieved only through a piece of legislation. The EU depends on multiple other factors for deconcentrating its supply chains.

II.) Lithium demand and price developments

The mining industry has experienced a significant transformation in the last half century. Following almost two decades of diminished demand for raw materials in the late twentieth century, the mining industry experienced a sudden surge in demand from China, particularly after its WTO accession in 2001. In 2005, Alan Heap, from Citigroup, argued that the mining industry was facing an upswing, a sustained, multi-decade "super cycle" of high prices (Heap, 2005). The economic rise of China, together with the emergence of the digital and energy transformations, have greatly affected the industry as a whole and more recently the markets of critical metals.

Lithium, for its part, once considered a relatively inconspicuous, low-cost metal attractive for its industrial use in the production of lubricants and heat-resistant glass and ceramics, has rapidly transformed into a highly sought-after commodity. During most of the 1990s, lithium prices remained low. Yet, as new applications in digital technology and electric vehicles (EVs) have surged, prices have also climbed (Maxwell, 2015). The evolution of lithium average prices between 2012 and 2023 is depicted below.

Figure 1. Evolution of Average Annual Lithium Prices 2012-2023



Source: Own elaboration with data from USGS (for 2019-2022) and Benchmark Mineral Intelligence (for 2023). Prices are in nominal USD and refer to lithium carbonate. Average annual prices for 2023 are calculated using data from January to October 2023

There are at least three elements in the lithium industry that have affected its prices, and which are important to consider for understanding the lithium landscape. First, lithium's sudden susceptibility to the EV market. Lithium's attractiveness began with the increasing adoption of portable devices in the nineties, but its transformation truly began with the increased attention to renewable energy. Currently, EVs account for approximately 40% of lithium consumption (Azevedo et al., 2018; Sun et al., 2018). As EV adoption continues to grow, the demand for lithium is expected to follow suit. According to Goldman Sachs Research (2023), EV sales are projected to reach about 73 million units in 2040, a substantial increase from around 2 million in 2020. EVs are anticipated to drive about 90% of lithium demand by 2040 (EIA, 2021).

The current demand for lithium is already intricately intertwined with the developments of the EV market. While its demand has been steadily growing, it has been subject to instability leading to notorious price fluctuations. As explained by Azevedo et al. (2018), the demand for EVs is fuelled by several factors: 1) public policy, including subsidies and regulatory frameworks; 2) urban infrastructure: a higher number of charging stations positively influences EV demand; 3) OEMs (Original Equipment Manufacturers) strategy: increasingly diversified range of EV models which cater to various consumer preferences; 4) battery costs: lower costs facilitate higher adoption rates; and 5) consumer preferences and prices: a reciprocal relationship impacted by the factors above. These, in turn, affect the demand for lithium.

Second, the massive influence of the Chinese market. While North American and European markets are important, the Chinese markets and government policy have had the largest influence on demand and prices (Azevedo et al., 2018). For instance, in early 2023, lithium prices experienced a sharp decline of 72% after China reduced subsidies for EVs, resulting in reduced demand and increased inventories (Onstad, Liu & Nguyen, 2023).

Third, the uncertainty about its continued use in the future, despite its current indispensability. Alongside EV adoption rates and supply-side responses, the outlook of the lithium industry is also influenced by the technology preferences of OEMs for battery compositions[2]. For instance, if emerging EV battery technologies like solid-state batteries—which require larger lithium proportions of lithium—become widespread, lithium demand will increase further. Indeed, since there are no foreseeable technologies to replace lithium in mass-produced car batteries, in the long term prices are unlikely to fall and remain low (Ewing & Krauss, 2023). Yet, it is in the mid-term that the lithium industry faces significant (price) uncertainties for mining companies, OEMs, and financial players (Azevedo et al., 2018; Ewing & Krauss, 2023).

Price dynamics are critical because they determine profit margins in the mining industry. Empirical studies indicate that price movements typically lead to changes in mining investments, including exploration and technological developments (Calzada Olvera & Iizuka, 2023). The lithium industry presents uncertainties about how prices will determine these investments. On the one hand, high lithium prices attract investors with optimistic profit expectations. On the other, lithium price peaks may stifle demand for EVs if battery prices reflect such peaks, potentially deterring future investments.

Furthermore, unlike commodities like copper or steel, lithium pricing mechanisms differ. Historically, pricing has been characterised by limited transparency and liquidity[3],[4]. Lithium has been historically priced using bilateral contracts in which long-term deals are based on volume and not prices (Azevedo et al., 2018; Maxwell, 2015). The expectation is, however, that as the lithium markets deepen, higher transparency in contracts and pricing will ensue. The introduction in 2021

[2] At the time of writing, there are five main competing lithium-ion battery technologies in the EV industry, each with different raw material blends. Each battery variant offers distinct performance characteristics based on the proportion of elements like nickel, manganese, and cobalt, catering to various EV requirements such as energy density, safety, and cost-effectiveness. Some of these blends have also emerged in response to the need of minimising cobalt – due to the many issues related to its supply (Azevedo et al., 2018).

[3] According to Maxwell (2015), lithium pricing may have become even more opaque in the mid-2015s as the lithium industry went from a cooperative oligopoly to a competitive oligopoly scenario. Given the massive increase in prices, new players have been attracted to enter lithium production. However, as stated at the outset, scaling up mineral production is a slow process.

[4] Low liquidity implies there are few players in the market, and transactions may result in larger price swings or difficulty in executing trades at desired prices. Liquidity is a critical aspect for investors as it affects their ability to enter or exit positions at favourable prices and influences overall market stability.

of cash-settled futures contracts for lithium hydroxide—one of the forms of processed lithium used in batteries—at the London Metal Exchange (LME) indicates that such expectations have begun to materialise.

The discussion above suggests that investment efforts must strategically factor in higher risks, surpassing the already inherent challenges characterising mining investments. Furthermore, amidst high uncertainty over the midterm horizon, investments should be guided by a "long-term greed" mindset (Azevedo et al., 2018). This perspective shift also requires new strategies from financial players to mitigate the financial risks of lithium mining ventures.

Notably, the inclusion of lithium as a critical raw material in the EU and the US, along with the establishment of strategic alliances, such as the Mineral Security Partnership, has been accompanied by intentions to boost investments and incentives for the lithium sector across various regions, notably Australia, Europe, North and South America. However, the impact of these investments and incentives on private sector investment, and the overall lithium sector development in South America remains to be seen.

III.) The case for investment in Latin America

To contextualise investment in the lithium sector, this section delves into the divergent pathways of industry development, offering insights into how state-driven decisions have moulded the present landscape of the lithium sectors in the focal countries under examination: Chile, Argentina, and Bolivia. Then, it presents an overview of key investment domains—primarily shaped by the geological characteristics of the region.

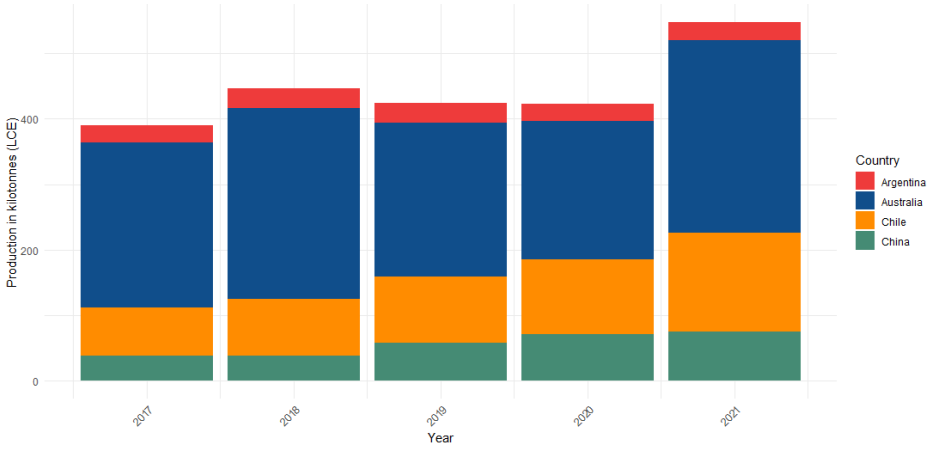
a. Lithium trajectory

The Andean region stands as a significant reservoir of global lithium reserves, boasting more than half (55.1%) of the world's resources and a substantial majority (84.5%) of brine reserves across its trans-border geological expanse. In the Lithium Triangle, unlike other parts of the world such as Australia, where lithium is extracted from hard rock, lithium is extracted from brines—highly concentrated saltwater located beneath the surface of salt flats.

Two key forms of lithium compounds are central to lithium battery production: lithium carbonate and lithium hydroxide. Both can be used depending on the specific type of battery required. There is no technological lock-in regarding which compound is preferred; the choice may evolve with changes in technology, supply chains, and battery prices (Azevedo et al., 2022; Silva, 2024). Currently, lithium carbonate, which can be used directly in EV batteries and serves as a precursor for the production of lithium hydroxide, is the most produced and traded compound.

The trajectory of lithium production, particularly in terms of volume, diverges significantly across the countries of the Lithium Triangle. Notably, Chile (30%) and Argentina (5%) have emerged as substantial lithium producers in 2022 (USGS, 2023), ranking second and fourth, respectively, in terms of global lithium carbonate production by volume. Figure 2 shows their respective share as top lithium carbonate producers. By contrast, Bolivia's lithium production is still incipient, having started a pilot project beginning of 2024. At the moment, Bolivia produces only 3-4 tons of lithium carbonate per day, which is not battery-grade[5].

Figure 2. Production Lithium: Top 4 Producers

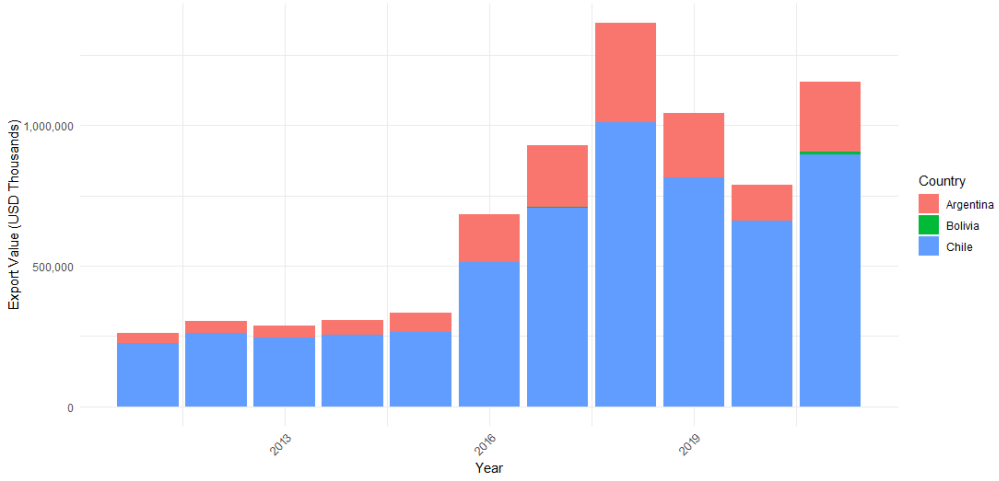


Source: own elaboration with data from the US Geology Survey 2021 data release. Figures refer to lithium carbonate or equivalent.

This divergence becomes particularly evident when examining lithium carbonate exports in 2021. Chile represented 61% of total exports, Argentina 17%, and Bolivia merely 0.8 % (Observatory of Economic Complexity, n.d.). Figure 3 shows the stark differences in terms of production capacity across the Lithium Triangle as reflected in exports.

[5] This means the purity of lithium is not high enough to be used in battery production.

Figure 3. Lithium Carbonates: Exports by Country (2011-2021)



Source: own elaboration with data from the Observatory of Economic Complexity

Furthermore, in terms of lithium hydroxide, Chile emerges as the regional contender with significant production, second only to China, which controls over half of global supply. In 2021, lithium hydroxide made up about 10% of Chile's total lithium production (Cochilco, 2021). That same year, Chile exported 8.7% of lithium hydroxide, trailing China's exports at 68% (Observatory of Economic Complexity, n.d.).

Finally, Argentina and Chile, despite having significant levels of lithium carbonate production and exports, exhibit a notable gap between their reserves (accounting for approximately 50% of total reserves in 2021) and their combined exports, which represent roughly a third of the total global exports. Chile, in particular, is facing more challenges compared to Argentina and is losing ground to Australia and China in the global market (Cochilco, 2021). With no new major projects planned for local production until after 2024, Chile is struggling to maintain its leadership (Cochilco, 2022). Meanwhile, Bolivia remains a marginal producer despite its lithium abundance.

b. What are the necessary investments to be developed?

Exploration

Although lithium is abundant globally and, in the countries conforming the Lithium Triangle, making exploration investments is crucial to ensure a sustained and secure supply of this metal in the mid and long term. Global lithium production witnessed a threefold increase from 2010 to 2020. Exploration operations, which heavily rely on increasingly sophisticated technologies, such

as digital geology applications and advanced drilling operations, represent one of the most costly and risky endeavours along the mining value chain (Calzada Olvera, 2021; Calzada Olvera & Iizuka, 2023). Expanding the resource base assumes critical importance due to the inherent nature of lithium operations, which, akin to other mining endeavours, are not agile enough to swiftly adapt to abrupt shifts in demand. Initiating new lithium mining projects, predominantly conducted through brine-based extraction in the Andean region, requires extended lead times. The process of ramping up production takes approximately four years and coupled with the extraction phase (brine concentration) of 10 to 24 months under current technological norms, even more. (Vera et al., 2023) This timeline does not account for additional fundamental steps in expanding new lithium operations, such as permitting, which can often take several years.

Furthermore, the industry's susceptibility to excessive concentration of lithium production requires the exploration and development of fresh mining operations (Azevedo et al., 2022; IEA, 2021). Notably, nearly 90% of lithium mining occurred in only three nations (Australia, Chile, and China) in 2021. In this context, diversifying the resource base through exploration, even within the Andean region, emerges as a crucial area of investment.

New extraction technologies

Technological investments are essential to profitable operations but, more importantly, these are essential to guarantee social and environmental sustainability. Without them, mining operations in the Triangle may stall or continue to be the subject of legal disputes and conflict with local communities. To understand why this is so crucial, one must consider the geological specificities about lithium extraction in South America, and its differences with rock lithium extraction carried out in Australia and some parts of China. In the latter countries, lithium is extracted from rock, in a process similar to other metals mining. By contrast, in South America, lithium is found in brines underground salt lakes or 'salares'. The extraction process, rather oversimplified, is that the brine is pumped out and brought to the surface to ponds where sunlight and wind evaporate the brine until lithium concentrations reach desirable levels. A point of contention with brine extraction is that, according to some estimates, it consumes 500,000 gallons of water per ton of extracted lithium, with about 95% of the extracted brine water permanently lost to evaporation (Kaunda, 2020)[6]. According to critics, this method can have adverse effects on water usage, flora and fauna,

[6] There is controversy about the methodology employed to measure water footprint. Given that due to the chemical properties of the brine it is not water that can be consumed or used for agriculture, it is argued that it should be excluded from water footprint measures. However, other authors contend that brine extraction can lower freshwater

waste generation, disposal, and land subsidence. In Chile's Salar de Atacama, water pumping increased by 21% between 2000 and 2015, leading to a depletion of local groundwater levels by as much as 1 meter per year in some areas (Kaunda, 2020). This poses risks of contamination in arid regions where groundwater is crucial for various purposes, including human consumption, livestock, crop irrigation, and native plant species. In all three countries of the Lithium Triangle projects have either been halted or subject to legal disputes due to overexploitation of water (Jerez et al., 2021; Lunde Seefeldt, 2020).

Alternative technologies are being studied that aim to protect the environment without compromising economic viability. These improvements involve various measures, such as water recycling, waste reduction, more efficient brine processing, smaller acreage footprints, transferable technologies, and minimising surface subsidence (Kuanda, 2020; Vera et al., 2023). In particular, evaporitic-alternative technologies—generically classified as direct lithium extraction (DLE)—promise not only to reduce water intensity in the process but also to boost lithium recovery rates and speed up brine concentration making extraction more economically efficient (Vera et al., 2023).

DLE technologies, however, remain highly underdeveloped with strong scepticism surrounding them—both from some industry players as well as communities[7]. This makes the need for innovative efforts to make DLE a commercially viable and environmentally sound technology. Miners such as Rio Tinto, Albemarle, and SQM; OEMs such as GM, Ford, and Renault; and specialised technology suppliers, are among those working on such technological developments (Scheyder, 2023; Seeking Alpha, 2023). Moreover, it is very likely that governments in the Lithium Triangle will move towards the gradual deployment of DLE as a requirement to operate in the region[8], making an even stronger case for ensuring a robust and sustained investment in the development of these technologies.

Processing

There is an equally important need for expanding lithium processing capacity. Regardless of the region, the extracted lithium must undergo further processing to make it suitable for various applications, such as battery manufacturing. While the choice for batteries in EVs and other

underground levels, which naturally flow into the brine, thereby affecting the overall water balance (see Vera et al., 2023)

[7] To this date all commercial DLE technologies require the use of evaporation ponds to further improve lithium concentrations. Furthermore, several DLE technologies have high levels of freshwater requirements in processing. This in turn has led to the development of a desalinisation plant construction that could offset such a downside.

[8] Chile has already proposed that the regulation will incrementally implement this type of technology.

consumer electronics may vary depending on the technology of choice, both lithium carbonate and lithium hydroxide have been in high demand (Azevedo et al., 2022). An important remark is that lithium extracted from brine ponds needs additional processing to become lithium carbonate. Further processing leads to lithium hydroxide, yet both forms of lithium can be used as input for batteries, as earlier explained. Further investments in this sector have been deployed in Australia (Covalent) and in the US (Livent) to expand their current capacity, but equally large projects in the Andean region are yet to be announced.

IV.) Risks

In this section, we discuss the risks that the EU faces in securing its lithium supply from the Lithium Triangle. Specifically, we discuss two kinds of risk that are particular to the region and that make difficult it's becoming a partner for the European union: concentration of players and regulatory frameworks.

a) Concentration of players

The industry is highly concentrated, with just a few firms —Albermarle, SQM, Livent, and Allkem—of American, Chilean, and Australian origin dominating production (see Table 1 below). In addition to the production of the region, these firms operate in countries where most of the global lithium extraction and processing occurs, namely Australia, China, and the USA. This underscores the geographical concentration of lithium production, which has already raised concerns about supply vulnerability (IEA, 2021). Furthermore, these mining companies are moving towards even greater concentration. For example, a merger announced by Livent and Allkem will position them as the third-largest lithium producer, behind Albemarle and SQM (Murdoch & Burton, 2023) . So, besides the geographical concentration, an oligopolistic structure of the lithium market—potentially more so than the standard mining and energy sectors— is also reflected in the lithium triangle. [9]

Such concentration has also raised concerns regarding competition risks. The Chinese lithium company Tianqi has a significant ownership stake in SQM. But it is also a direct competitor and, with Albemarle, co-owns Talison Lithium—one of the largest lithium operational sites in Australia and globally. This is reported by SQM as a key investor risk: "Tianqi is a significant

[9] This structure has been traditionally characteristic of the lithium industry: In the 1990s, the lithium industry was dominated by only three firms: Cypress Foote Mineral Company, FMC Corporation, and Sons of Gwalia (Maxwell, 2015). Through rebranding, acquisitions, and mergers, these companies transformed into Albermarle, Livent, and Talison Lithium (the joint venture of Albermarle and Tianqi).

shareholder and a competitor of the Company, which could result in risks to free competition." (SQM, 2022).

In addition to the oligopolistic structure of the market, there are vertical integrations taking place along the value chain. For instance, Japanese and Chinese companies are making significant efforts to establish a foothold in the supply of lithium via investments within the battery automotive industries and battery manufacturing sectors. Toyota and other OEMs are making notable investments to secure lithium supply – either through co-ownership of mines and/or processing sites or via long-term contracts. Notably, Toyota has ensured a stable supply of lithium from Argentina, through a 25% stake in the Salar de Olaroz, Argentina. Lithium carbonate sourced from the Olaroz site is processed at the Naraha-machi facilities in Japan, where a 10.000 tons/year production of lithium hydroxide has been established. The sales of this lithium is exclusively managed by Toyota's subsidiary, Toyota Tsusho Corporation, with most of the production expected to be delivered to the Japanese battery industry (Toyota Tsusho Corporation, n.d.) Similarly, GM, BMW, and Tesla have secured multiyear contracts with Livent to ensure their lithium supply (Barrons, n.d.; GM, n.d.; Nica, 2021). GM has chosen lithium extracted from Livent's operations in Argentina to support its EV production goals in the North American market (GM, n.d.). This strategy explains—at least partially—why amidst short-term turbulence in lithium price developments and EV industry developments, the lithium industry has managed to keep expanding its capacity and accompanying investment requirements. In the future, industries and markets that did not invest directly, in the way OEMs have done for instance, may face fewer supply options or much higher prices. Finally, the disclosed Chinese investments in the region suggest a growing presence and resource access. Given these developments, it remains unclear what efforts the European Union is making in the Lithium Triangle to secure its access to lithium supply.

Table 1. Firm stakeholders and their capacity in lithium production

Operational Sites	**Ownership and Carbonate Lithium Production**	**Further Processing Site and/or Firms**
Salar de Olaroz, Argentina	The Olaroz Lithium Facility is operational and expanding, with Allkem from Australia as the majority owner with a 66.5% stake. Toyota Tsusho Corporation (TTC) (Japan) holds 25%, and Jujuy Energía y Minería Sociedad del Estado (Argentina, state-owned) holds 8.5%. This joint venture is also known as Orocobre.	All lithium carbonate production is exported. A joint venture (Nahara) with Toyota aims to process most of the Olaroz production for the Japanese market.

	In 2022, this facility produced 16,000 metric tons of Lithium Carbonate (Toyota Tsusho Corporation, n.d.). It is expected to reach up to 42,000 metric tons with its current expansion.	
Salar del Hombre Muerto, Argentina	The Proyecto Fenix is operational and expanding, with Livent (USA) as the sole owner. The production in 2022 was approximately 20,000 metric tons. A merger between Allkem and Livent is expected by the end of 2023. (Livent, n.d.)	All lithium carbonate production is exported. Livent processes lithium in its facilities in the USA; Livent's processing sites are planned to be developed or under development in Canada and China. Livent also has agreements with GM and BMW to supply lithium for EV batteries.
Sal de Vida, Argentina	This project is in the development phase and is wholly owned by Allkem. (Allkem, n.d.) Battery producer POSCO (South Korea) acquired tenements when it was still owned by Galaxy Resources Limited (Australia).	--
Salar de Uyuni, Bolivia	While not fully operational, Yacimientos de Litio Bolivianos (YLB), a state-owned entity, owns 100% of this project and produced 600 metric tons of Lithium Carbonate in 2022. YLB also selected the Chinese consortium, CATL BRUNP & CMOC (CBC), to hold the exploitation rights for a $1 billion agreement. (Mining Technology, 2023; C&EN, 2023)	China and Bolivia have planned the development of all lithium processing and subsequent manufacturing of batteries in Bolivia.
Salar de Atacama (SQM)	SQM mines are fully operational, producing 156,000 metric tons of Lithium Carbonate in 2022. SQM's main (non-institutional) shareholder groups are the Pampa group (Chile) with 26%, Tianqi (China) with 22%, and Kowa Group (Japan) with 2%. SQM plans to expand its capacity to reach 210,000 metric tons of lithium carbonate and 40,000 metric tons of lithium hydroxide by 2023, with the latter reaching 100,000 metric tons by 2025 (SQM, 2022).	SQM owns a processing facility in which it produces lithium hydroxide (approximately 10% of total Chilean carbonate production).
Salar de Atacama (Albemarle)	Albemarle (USA) produced 50,000 metric tons of Lithium Carbonate in 2022. Expansion plans aim to reach 85,000 tons in 2023 (Cofré, 2023).	It owns lithium hydroxide processing plants in several countries (including three in China, one in Australia, and one in the USA), but none in Chile. (Albemarle, n.d.)

Source: Own elaboration. Note: Lithium production is expressed as gross weight.

b) Regulatory framework

The three countries in the Triangle have different histories concerning the policies they have developed for their mining industries, which today reflect different approaches to their mining and development strategies. While describing these divergent histories is beyond the scope of this paper, we analyse some of the current risks each country has towards their lithium industry and how this potentially affects the region as a reliable partner for the supply of lithium for the EU.

Empirical studies indicate that a competitive investment climate tends to attract mining investments more than the sheer abundance of mining commodity reserves (Vásquez Cordano & Prialé Zevallos, 2021). Indeed, according to the Fraser Institute, which conducts an annual survey among mining companies about how mineral endowments and public policy factors affect exploration investment, mining companies attribute 40% of importance to policy aspects in their exploration decisions (Mejía & Aliakbari, 2023).

When it comes to the development of the lithium industry, besides the technical issues stemming from the geological conditions of extraction and conflict with local communities, the policy strategies adopted by these countries are equally important. For instance, the degree of control exerted by the state over lithium resources and the level of openness to private investment and public-private partnerships, have significantly influenced the development of the lithium industry in the region (ECLAC, 2023).

Given the recent developments that have brought lithium to the forefront of the green transition, lithium has gained the status of 'strategic resource' in all three countries[10] (ECLAC, 2023). Nonetheless, the regulatory framework that stipulates how lithium is to be exploited differs substantially. Table 2 below summarises the differences.

Table 2. Regulatory framework of lithium-related activities

	Type of Regulation	**Governance Framework**	**Regulatory Scope**	**Resource Exploitation Modes**
Argentina	General Mining Legislation (with province-level legislation)	Province-level (Federal)	Activities related to resource extraction	Concessions to Private Companies Participation by the Provincial State Enterprise in Jujuy: Jujuy Energy and Mining State Company (*JEMSE*))

[10] Though in Argentina such a status has been granted only at the provincial level (in Jujuy and La Rioja).

Bolivia	Lithium Declared a Strategic Resource. Lithium-specific legislation.	Centralised	Activities related to resource extraction and industrialisation (i.e., processing and manufacturing)	Public Enterprise (Yacimientos de Litio Bolivianos (YLB))
Chile	Lithium declared of national interest or 'a Strategic Resource'. Lithium-specific legislation.	Centralised	Activities related to resource extraction and, through the Corporation for Production Promotion (CORFO), with a quota reserved for industrialisation.	Lease contracts between CORFO and private actors (currently only two firms: Albermarle and SQM). Possible modalities, but not currently applied: the State or its companies, or through administrative concessions or special operation contracts to third parties.

Source: Adapted from ECLAC, 2023

Chile

Despite a complex regulatory environment, Chile has been considered a country with a favorable business environment, relatively low levels of bureaucracy, and minimal corruption (Lunde Seefeldt, 2020), attracting substantial foreign investments. The country is home to two major global players: SQM (Sociedad Química y Minera de Chile), partially owned by the Chinese lithium miner Tianqi (22.1%), and the American company Albemarle. Both companies have a strong presence in the global lithium market.

The complexity of Chile's regulatory framework for lithium exploitation arises from the division of regulations into two distinct periods: pre-1979 and post-1979. Before 1979, lithium was not considered a strategic mineral, allowing private companies to obtain concessions for lithium extraction under the same conditions as for other minerals. This framework enabled SQM and Albemarle to acquire rights to extract lithium from the Salar de Atacama, continuing their operations under the conditions established prior to 1979. However, in 1979, lithium was declared a mineral of national interest (DL 2886) due to its potential use in nuclear technologies, making it non-concessible. This change meant that new mining concessions for other minerals no longer automatically included the right to extract lithium.

Currently, lithium exploitation in Chile is limited to the State, its companies, or private entities through Special Lithium Operations Contracts (CEOL) granted with authorization from the Ministry of Mining on behalf of the President of the Republic, or through Administrative Concessions. Additionally, the commercialization of lithium products produced in Chile requires

authorization from the Chilean Nuclear Energy Commission (Cochilco, 2021). Consequently, SQM and Albemarle's current operations are based on their earlier concessions, but they must comply with periodic renewals and adhere to updated regulatory requirements.

More recently, in 2023, Chile announced its National Lithium Strategy, which includes its intention to move beyond lithium extraction and processing by establishing its own manufacturing ecosystem centred around lithium via preferential treatment for foreign investors willing to transform lithium into products of higher added value in the country (Leali, 2020). This strategic shift has raised concerns within the European Union, as it is perceived to potentially limit the EU's ability to secure a reliable supply of lithium compounds for its battery production, potentially impacting future investments. Notably, this approach is not unique to Chile, as other lithium-rich regions, such as Quebec in Canada, have also expressed their commitment to prioritise processing over exports of the raw material through similar policies (Gouvernement du Québec, n.d.).

Chile has also taken other measures aimed at securing more benefits from its lithium production through other industrial policies. A key component of this strategy was the creation of a National Lithium Company (NLC), intended to facilitate the Chilean state's participation in lithium-related activities in the Salar de Atacama, where SQM and Albemarle currently operate. The formation of the NLC is subject to congressional approval, and while the strategy aims to increase Chile's lithium production, it brought uncertainty regarding the exact role of the NLC, and the terms under which it would partner with private investors. This uncertainty particularly affected SQM, which has a concession to operate until 2030 and faced significant risks, as its concession might not be extended or the terms might not be favourable to its business (SQM, 2023)[11].

As stated above, the lithium industry has significant opportunities to sustainably increase supply. However, uncertainty regarding the regulatory framework could hinder (international) private investment. Despite this uncertainty, there is not necessarily a higher risk of curtailing lithium production in Chile. The country is home to numerous examples of successful national companies, such as Codelco, which have access to substantial financing from international markets.

[11] Under the National Lithium Strategy, Codelco was designated by CORFO to lead negotiations with SQM to seek participation in SQM's operations in the Salar de Atacama before the expiration of its lease agreement in 2030, in exchange for an extension of SQM's contract to continue exploiting and producing lithium in the Salar de Atacama. On December 27, 2023, SQM and Codelco signed a nonbinding Memorandum of Understanding, which established a framework for the terms and conditions of definitive agreements for a joint venture. This joint venture would allow SQM's subsidiary, SQM Salar, to continue exploiting mineral resources in the Salar de Atacama until 2060. CORFO granted Codelco's subsidiary, Minera Tarar, the rights to exploit the Salar de Atacama from 2031 to 2060, which will be contributed to the joint venture. If the parties are unable to agree on definitive agreements, either the Chilean government or SQM could allow the lease to expire in 2030, following its terms (SQM, n.d.).

Argentina

In contrast to Bolivia and Chile, Argentina's regulatory framework is particularly friendly towards foreign investment in the lithium sector. First, the 1994 National Constitution acknowledges provincial jurisdiction over natural resources, including lithium. This implies that each province has ownership of its minerals and is free to contract with third parties. In practice, this gives provinces less bargaining power against multinational companies. It also results in policy inconsistencies across different provinces. Second, the Mining Code allows private entities to obtain concessions for lithium exploitation. Third, the Mining Investment Law promotes investment in the industry through tax incentives and 30-year tax stability (Urzúa, 2013).

However, many macroeconomic policies established in the governments of first, Néstor Kirchner and then Cristina Fernández between 2003 and 2015, have had detrimental effects on foreign direct investment in Argentina. They employed, for instance, export taxes and import controls which hampered companies' ability to send profits back to their headquarters and required companies to apply for permissions to import equipment (Lunde Seefeldt, 2020). While many of these policies were repealed during Mauricio Macri's government (2015-2019) "soothing investors' nerves and welcoming in foreign investment in the lithium sector" there is again pessimism among investors about the investment climate in Argentina. According to the Fraser Institute Mining annual survey, Argentina declined 17 points in its Policy Perception Index, which examines fifteen policy factors such as uncertainty concerning the administration of current regulations, the legal system and taxation regime, uncertainty concerning protected areas and disputed land claims, and trade barriers (Mejía & Aliakbari, 2023).

Currently, the major players in Argentina include the American company Livent and the Australian mining company Allkem. Recent investments in Argentina include a $73.5 million project by Jiangxi Ganfeng Lithium Industry – the third largest mining firm in the lithium sector, a $70.1 million expansion by Canada's Neo Lithium Corp in Salta and Catamarca provinces, respectively, and a $380 million investment by the Chinese-owned Zijin Mining Group Co., Ltd. in 2022 (ECLAC, 2022).

Bolivia

Bolivia has long aspired to establish a robust battery industry centred around its vast lithium reserves. This ambition took shape in 2006 with the National Development Plan introduced by former President Evo Morales (2006-2019), which aimed for "a new understanding

of the development of economic policies and strategies that shall establish a new pattern of development; a new social and communitarian focus; a new productive matrix and the insertion in international markets […] to eliminate poverty and social exclusion"[12] (PND, 2007). A core aspect of Morales's vision was a policy of resource nationalism, characterized by efforts to maximize economic benefits through higher taxes, restrictions on foreign ownership of mining assets, and export controls. This strategy sought to ensure that Bolivia retained full control over its mineral wealth, including lithium. Morales enshrined the nationalization of mineral resources in Bolivia's new constitution (Davis, 2020), committing to a vision where a state-owned company would manage the entire value chain from lithium extraction to battery production, explicitly excluding international partners.

While this approach was aimed at securing maximum economic benefits for Bolivia, it also represented significant challenges. The policy of resource nationalism, while not unique to Bolivia and observed in other mineral-rich countries during the mining boom of the early 2000s (Humphreys, 2015), has often deterred foreign investment and complicated efforts to develop Bolivia's lithium industry on a global scale.

The state-owned enterprise, Yacimientos de Litio Boliviano (YLB), was only established in 2017, a full decade after the initial plans were laid out. YLB's strategy aligned with Morales's nationalistic approach, seeking to maintain sovereignty over Bolivia's lithium resources. Yet, since then, YLB has faced significant challenges in developing its lithium industry, largely due to a lack of critical infrastructure for extracting and processing battery-grade lithium. Bolivia's unique climatic and geological conditions, such as higher concentrations of magnesium in its brines, complicate lithium extraction (Lunde Seefeldt, 2020), increasing the level of investment required to effectively adapt extraction processes to these conditions while making its lithium quality and cost competitive. Moreover, Bolivia's efforts are further undermined by systemic issues such as corruption, a weak rule of law, and a lack of legal security, which deter foreign investment and hinder the industry's development.

In 2018, YLB attempted to jumpstart its lithium ambitions by signing a $250 million agreement with German company ACI Systems. This agreement, however, was abruptly cancelled in 2019 following a decree by Morales (Bos & Forget, 2021). In response to this, YLB shifted its approach and, in 2023, announced a new partnership with the CBC consortium, led by China's CATL, a leading battery manufacturer. This consortium, which also includes CATL's recycling

[12] "una nueva concepción del desarrollo de políticas y estrategias económicas, que establecerán un nuevo patrón de desarrollo; un nuevo enfoque social y comunitario; una nueva matriz productivay la inserción internacional […] para erradicar la pobreza y la exclusión social." (PND, 2007, own translation)

subsidiary BRUNP and the mining company CMOC, committed to a $1 billion investment to establish two industrial complexes capable of producing 25,000 metric tons of lithium carbonate annually (Mining Technology, 2023; YLB 2023b). Despite the shift towards international partnerships, YLB emphasized that this investment adheres to a "sovereign investment model" that respects Bolivia's sovereignty and includes YLB at every stage of the value chain (YLB 2023a).

This new partnership represents Bolivia's renewed effort to capitalize on its lithium resources and overcome the challenges of previous attempts. However, there remains considerable scepticism regarding the potential success of this partnership due to Bolivia's history of failed public-private initiatives (Lunde Seefeldt, 2020; C&EN, 2023).

In line with the risk outlined above, additional concerns related to regulatory frameworks and other critical factors have been assessed for mineral investments across Latin America, including the Lithium Triangle. These risks include the availability of specialized labour, infrastructure, and overall confidence in the mining sector (Economist Intelligence Unit, 2024). According to these assessments, Chile and Argentina rank as the first and second most attractive destinations for investment in this critical sector. This ranking suggests that, despite differing regulatory approaches, both Chile and the Argentine province of Jujuy remain strategic for lithium sector investments. In contrast, Bolivia faces challenges not only in its regulatory environment but also in other areas, resulting in its ranking as the least attractive among Latin American countries for investment in the lithium industry (Economist Intelligence Unit, 2024).

V.) Conclusions

Europe is estimated to face a shortage of lithium of about 300,000 metric tons by 2030. The Lithium Triangle is in a particularly strategic position to potentially be able to close this gap, for three important reasons. First, it is geologically endowed with the mineral. Second, its institutions are relatively well developed to generate the interest of foreign investment. Third, it contributes to deleveraging from the geopolitical risk between the EU and third countries.

However, several challenges and bottlenecks make the region's position particularly fragile. First, the lithium market is characterised by an oligopolistic structure dominated by a few major players. The concentration of power in the hands of a few companies – and only in a handful of countries – represents an important potential source of supply vulnerability, hindering the EU's efforts to secure a reliable supply chain, as stipulated in its Critical Raw Materials Act.

Second, a small number of OEMs—so far none of European origin—have strategically invested in lithium mining companies to secure their supply. This development jeopardises Europe's access to lithium, as these firms might prioritise their own needs and interests over external demands, potentially leaving European industries with fewer supply options or facing much higher prices.

Third, the environmental impact of lithium extraction, particularly the water-intensive brine extraction method used in the Lithium Triangle, poses significant sustainability challenges. The method is said to consume vast amounts of water, leading to the depletion of local water sources and raising concerns about the well-being of the populations nearby and thus about the long-term environmental viability of lithium mining in arid regions. Although there is high interest in developing direct lithium extraction (DLE) technologies that promise lower water usage and higher efficiency, these technologies are still in their nascent stages and require significant investment, innovations, and testing for being implemented at an industrial scale.

Fourth, the regulatory environment in the Lithium Triangle is marked by divergent policy frameworks. Bolivia's resource nationalism approach has kept a stringent control over its lithium resources in attempt to maximise its benefits, yet an overall weak institutional and infrastructure capacity, has severely limited its production capacity. Chile's recent moves to adjust its regulatory framework to support more ambitious industrial policies have created uncertainty in some areas – especially regarding the lease concessions that the State has granted current companies. Argentina presents a more investment-friendly climate, though it still faces governance challenges and policy inconsistencies at the provincial level, which could impact investor confidence.

The EU has been largely absent from the investment landscape in the Lithium Triangle, an approach that conflicts with its objectives under the Critical Raw Materials Act. Ensuring a stable and sustainable lithium supply chain requires moving beyond policy initiatives and nonbinding discussions toward concrete actions, a step largely avoided by Europe at the time of writing. A commitment to equitable economic development in the Lithium Triangle, potentially through collaborations focused on technological sharing, capacity building, and joint ventures, could mitigate risks associated with supply concentration and reduce the environmental impact of the industry. However, these strategies remain underdeveloped in the current investment landscape, raising questions about the feasibility of the EU's ambitious green goals amidst geopolitical and industry-level risks.

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