71 WORKING PAPER

The criticality of lithium and the sustainability-finance nexus: Supply-demand perceptions, state policies, production networks, and financial actors

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Content

List of Abbreviations

A2Z	Accelerating to Zero Coalition
ASX	Australian Stock Exchange
BMI	Benchmark Mineral Intelligence
BMW	Bayerische Motoren Werke
BYD	Build your dreams
CATL	Contemporary Amperex Technology
CIF	cost insurance freight
COP26	26th UN Climate Change Conference
CME	Chicago Mercantile Exchange
DRC	Democratic Republic of Congo
EBA	European Battery Alliance
ERMA	European Raw Materials Alliance
ESG	Environmental, social, and corporate governance
ETF	exchange traded fund
EU	European Union
EuGB	European Green Bond
EV	Electric Vehicles
DLE	direct-lithium-extraction
FDI	Foreign Direct Investment
GBS	Green Bond Standard
GFANZ	Glasgow Financial Alliance for Net Zero
GPN	Global Production Network
IPCEI	Important Projects of Common European Interest
LFP	lithium-iron-phosphate
Li_2O	lithium oxide
LME	London Metal Exchange
NGO	Non Governmental Organization
PRA	Price Reporting Agencies
SGX	Singapore Exchange
SQM	Sociedad Química y Mineral
TSX	Toronto Stock Exchange
YLB	Yacimientos de Litio Bolivianos

List of Figures and Tables

Abstract

The eco-technological fix to the climate crisis renders certain resources, such as lithium, as 'critical'. We argue that criticality is actively produced in socio-technological processes, involving three interrelated levels – demand, supply and price perceptions, policies linked to green extractivism, and underlying narratives around the role of commodities in development. Criticality is interrelated with firm strategies in global production networks (GPNs) as well as financial actors' strategies, legitimizing extractivism for sustainability transformations. We highlight the role of financial actors and interests in enabling lithium expansion and assess two channels through which financial actors shape producer strategies and GPNs – financing and price-determination. Driven by criticality, financial actors mobilize 'green' investment stories along the sustainability-finance nexus. This enables the shifting of extractive frontiers through funding new projects and creates variable price-setting regimes linked to derivative markets. Financial interests introduce an additional speculative momentum to lithium extraction, contributing to accelerating boom-bust patterns and short-termism. Methodologically, the paper draws on sector data, industry and company reports, as well as semi-structured interviews with lithium sector and financial actors in London, Switzerland, Chile and Zimbabwe.

Key words: green extractivism, lithium, criticality of resources, sustainability-finance nexus, global production networks

1. Introduction

Since 2020, pronouncements of a new commodity super-cycle have been on the rise. While the changing geopolitical context, accelerated by the COVID-19 pandemic and the Russian invasion of Ukraine, and related uncertainties and supply disruptions are important drivers, the current commodity boom is also linked to policies around 'sustainability transformations'. A majority of countries in the Global North and South has pledged large-scale decarbonization efforts to reach the 2-degree goal of the Paris Agreement and, to achieve this, there are high hopes placed on 'green' technologies. Particularly ambitious pledges have been made concerning electro-mobility. During COP26, over 100 countries, cities, financial institutions and transnational corporations agreed on ambitions to reach 100 % zero-emission vehicles by 2040, and by 2035 in 'leading markets', which was followed by the creation of the Accelerating to Zero Coalition (A2Z) at COP27[1].

Such ambitions and related policies have rendered certain technologies linked to decarbonization and electrification – such as electric vehicles (EV) and stationary forms of energy storage for renewable wind or solar energy and the battery systems underlying them – as crucial ingredients of 'green' futures (Bridge/Faigen 2022; Riofrancos 2022). Transformations based on these technologies are changing the commodity-mix demanded and rendering specific minerals such as lithium, cobalt, nickel, copper and graphite as 'critical resources' (Voskoboynik/Andreucci 2022). Particularly lithium has become the 'super-commodity', frequently referred to as 'white gold' or 'white oil', transforming it in a very short time from a niche chemical to a 'critical mineral'. This can be exemplified by growth in extraction, which increased by almost six times between 2000 and 2020 (Reichl/Schatz 2022).

Lithium 'criticality' also encompasses its 'greenness', focusing on the contributions of lithium-based technologies to lower emissions and climate risks. This allows collapsing economic, political, social and environmental parameters into this single term that is "operational at the political level" (Machacek 2017: 317), obscuring the extractive element of lithium production and side-lining concerns related to resource extraction and use (Dorn et al. 2022; Riofrancos 2022). More broadly, ongoing sustainability transformations do not challenge the growth and development model based on extractivism, but substitute it with a 'green' investment story built around 'green' technologies. This technological determinism where technology advancement serves as an imperative of change is not only visible in current narratives around sustainability transformations, but has served more generally as a crisis strategy to address labor, social or environmental 'problems', termed as 'technological fix' (Harvey 2003), this time occurring as an 'eco-technological fix' (Dietz et al. 2022).

The contradictions around current sustainability transformations and eco-technological fixes have been the focus of an increasing literature around 'green extractivism', arguing that sustainability transformations, largely driven by countries of the Global North, re-create uneven development outcomes by externalizing negative economic, social and environmental consequences of resource extraction, this time under 'green' banners, to the Global South (Claar 2022; Dorn et al. 2022; Zografos 2022).

We build on this literature arguing for the analysis of the making of criticality by different actors, reflecting their interests and power relations. Following Bridge (2009), we argue that 'criticality' is made in socio-technological processes that turn a material into a resource or a 'critical' resource. Critically is made by articulations of (i) supply, demand and price perceptions, which are not objective and readily read of from 'markets', but emerge in a highly uncertain context, (ii) geo-politically- and environmentally-motivated policies at different levels of lithium-battery-EV global production networks (GPNs) in the Global North and South, and (iii) narratives and imaginaries around the use of lithium in broader development and transformation processes.

[1] https://impact.economist.com/sustainability/net-zero-and-energy/progress-on-cop26-pledges-zero-emission-vehicles; https://acceleratingtozero.org/accelerating-to-zero-a2z-coalition-launches-at-cop27-to-drive-global-transition-to-zero-emission-vehicles/

The making of criticality along these three levels impacts the strategies of firms engaged in lithium production but is also shaped by them, leading to new firms entering and changing firm constellations and power relations in GPNs. Financial actors fund the expansion of lithium production, and have a strong interest to profit from financing and investment activities around 'booming' and also 'green' commodities and thereby shape producer firm strategies and outcomes in GPNs and producer countries.

We particularly highlight the generally side-lined role of financial actors and interests and assess two channels through which financial actors shape producer strategies and GPNs – financing and price-determination. Building on Riofrancos (2022) security-sustainability nexus and Franz/McNelly (forthcoming) finance-extraction-transitions nexus, we argue that financial actors mobilize 'green' investment stories along the sustainability-finance nexus. This enables the shifting of extractive frontiers through funding of (often high-risk) projects and creates a variable price-setting regime in lithium GPNs, potentially introducing financial speculation on derivative markets. Such an engagement by financial actors is possible because of the criticality of lithium; as said by a sector expert "if it would be a boring, non-critical, mineral, the producers would not get access to green bonds and equity markets that easily". These financing relations led to pressure by financial actors in the form of shareholder value or as creditors, contributing to accelerating boom-bust patterns and short-termism with problematic economic, social and environmental outcomes in producer counties.

Through this analysis we contribute to the literature on the shifting perception of finance in debates around sustainability transformations and criticality of resources, where financial actors are perceived as enablers of the 'eco-technological fix' by mobilizing and channeling capital to green investments, importantly through environmental, social and governance (ESG) considerations and green bonds (World Bank 2021). This shift side-lines the speculative logics and destabilizing and detrimental outcomes of (global) finance generally and in the lithium sector specifically.

Methodologically, the paper is based on production, trade and financial data, industry and company reports, as well as semi-structured interviews. Interviews were conducted with metal sector actors (mining companies, international traders, industry associations and experts) and financial actors (London Metal Exchange (LME), price reporting agencies (PRAs), financial investors and experts) as well as producer country actors (Ministries and other state institutions, sector associations, artisanal mining cooperatives, industry experts, NGOs). Interviews focused on actors in the central metal trading hubs London and Switzerland as well as the lithium producer countries Chile and Zimbabwe. Altogether, 35 interviews were conducted in the lithium sector between 2021 and 2023.

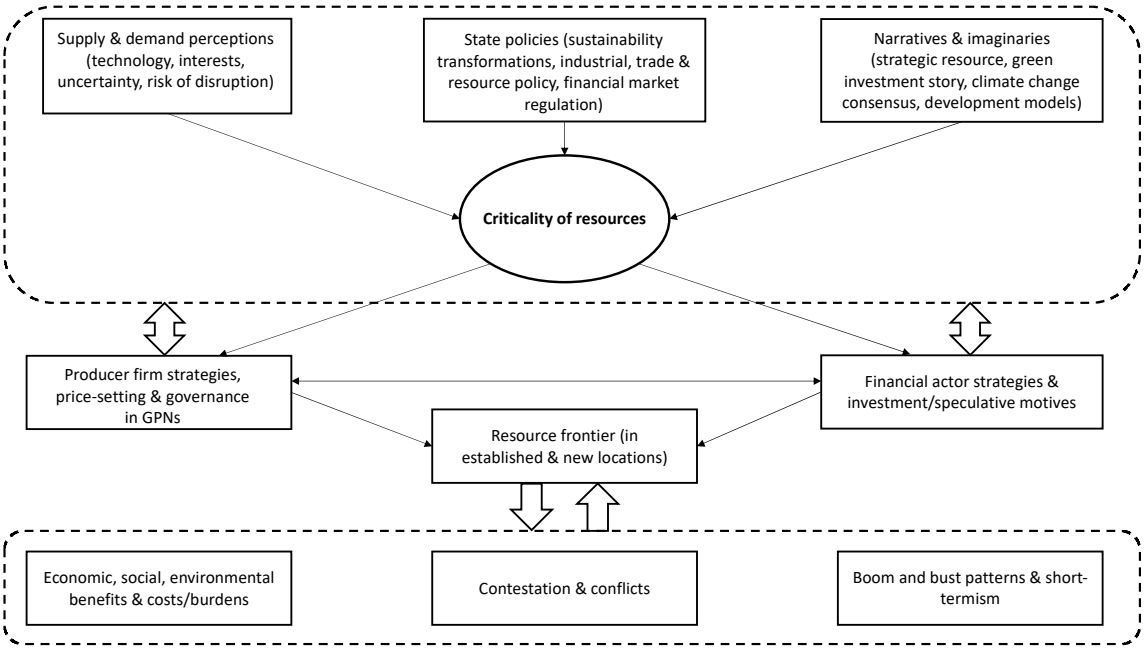
In the next section, we develop our conceptual argument on the making of criticality. Section 3 substantiates our argument with empirical insights on the criticality of lithium. The last section concludes.

2. The Making of Criticality

Building on Zimmermann (1933), Bridge (2009: 1220), Bos/Forget (2021: 3) and others argue that "resources are not; they become" to highlight that such resources are actively 'made' in socio-technological processes (Huber 2021). Also 'criticality' is produced, as (Machacek 2017: 368) writes, "in a 'bureaucratic practice of classification', (where) 'key materials' are turned into 'critical materials'". (Riofrancos 2022: 5) adds that "'criticality' is less a stable condition than an emergent outcome of interacting variables: the discovery of deposits, the development of new extraction methods, government promotion of EVs, evolving battery chemistries, and recycling capacity, among others." As shown in Figure 1, we argue that the making of criticality in socio-technological processes involves three interrelated levels – (i) supply, demand and related price perceptions that are mediated by technology, (ii) geo-politically- and environmentally-motivated policies at different levels, and (iii) narratives and imaginaries around lithium's

broader role in development. A 'risk of disruption' related to perceptions on the availability of materials in the market at acceptable prices (Machacek 2017: 369) forms a necessary basis for making criticality, that is however only enacted through policies that are reflective of broader narratives. Criticality reflects different strategies and interests of actors, and can be mobilized by them to different ends, but it also impacts on producer firm and financial actor strategies that are interdependent and shape extractive frontiers, and related economic, social and environmental outcomes, contestation and conflict, and boom-bust patterns. The strategies of these actors, in turn, also impact on how criticality evolves through shaping supply, demand, technology, price-setting, etc.

Figure 1: Conceptual framework on criticality of resources



Source: Own elaboration

First, supply, demand and price forecasts are the basis of determining the 'risk of disruption'. However, establishing predictions on resource availability is not a merely technical or objective process and even more so in the uncertain and booming context of lithium extraction. New extractive projects in new geographical frontiers, the entrance of new actors and technological developments make it difficult to project supply and demand for lithium. Sector specialists such as PRAs produce reports on demand and supply forecasts together with consultancy firms (e.g., McKinsey) and independent analysts which largely operate via Twitter, podcasts or their websites, with the yearly scenario reports by the International Energy Agency (IAE) being also highly influential. These actors have specific insights into lithium developments, but also follow their own strategies and subscribe to certain narratives around desirable development trajectories and imaginaries of the role of lithium within them and, hence, exert power in 'reporting' (and determining) supply, demand and price data. Determining prices is even more difficult and contested, and requires looking behind what is generally used as the world price for certain commodities (Wojewska et al. forthcoming) For lithium, PRAs and derivative markets play a crucial role in these processes and they are influenced by financial actors' interests to invest in lithium futures and shift to short-term price-setting in contracts.

Second, states and their regulations and policies play a key role in the making of criticality. Current policies around sustainability transformations and electro-mobility have not only made specific materials such as lithium to central components of these transformations and hence created demand in the first place, but also impact on GPNs from extraction to battery production to EV manufacturing. State actions secure the conditions for accumulation around

new products, technologies and infrastructures through their multiple functions and roles as facilitator, regulator, producer, and buyer (Horner 2017). Hence, state action cannot be thought of as 'policy' but needs to go beyond to understand policy "as the outcomes of struggles within the state at different spatial scales and between the institutions of the state and other social formations" (Bridge/Faigen 2022: 8 drawing on Jessop 1990). Lithium-consuming countries follow various considerations beyond sustainability motives, most importantly securing (unrestricted) access to supply abroad and also domestically and developing own battery production capacities. Onshoring of lithium and battery production has been supported by 'green' industrial policies (Roberts et al. 2019), bringing in sustainability as a geopolitical factor in the competition between states, what Riofrancos (2022) terms the 'sustainability-security nexus'. Explicitly citing competition with China, policies focus on de-risking of 'green' investment and other corporate-friendly policies to stimulate onshoring of lithium extraction and battery production. Importantly, policies around 'green' finance (e.g., green bonds, ESG considerations) are also presented as central in securing access to and investments in critical minerals and redirecting capital flows to sustainable investments (World Bank 2021). Policies around criticality are also made in lithium-producing countries. Unlike during earlier periods, which prioritized a reduced role of the state, states play generally also more active roles in attracting (foreign) investments but also furthering local value addition or resource nationalisms, that are articulated to different degrees in different producer countries (Dorn et al. 2022; Svampa 2015).

Third, these policies enacted by states, are linked to and based on broader narratives and imaginaries around resources. For lithium, (Barandiarán 2019: 382) distills different sociotechnical imaginaries, i.e., its political values and meanings accredited to by science and technology – "(1) lithium as a banal, market commodity; (2) lithium as a strategic resource; and (3) lithium as the subject of a sociotechnical imaginary that reimagines how mining can serve development goals.". Also referring to lithium, Dorn et al. (2022) argue that there has been a shift from the 'commodities consensus' (Svampa 2015: 2) to the 'climate change consensus', which centers technology as a means of climate protection, justifying extractive activities not only as imperative but also 'green' and denying possibilities for other meanings of development. Importantly, "in regions of extraction, the climate change argument adds a new layer of legitimacy to the classical development paradigm, leading to the acceptance of social inequality and environmental destruction", as the climate change consensus relies on "a non-ideological reframing of commodity extraction beyond political camps" (Dorn et al. 2022: 3). Beyond lithium-producing countries, the electro-mobility transformation works as a narrative, legitimizing green extractivism abroad and domestically. Attached to these narratives are green investment stories in which financial actors are perceived as enablers of the 'eco-technological fix' by mobilizing and channeling capital to sustainable investments. Green finance can be understood as "an attempt to reconcile (…) environmental tensions through financial products" (Wooldridge 2022: 7) and approach "climate risk (a)s financial risk" (Christophers 2019: 761), treating financial actors as imperative to the success of the 'eco-technological fix'. Such imaginaries, consensus or stories are the basis for policies supporting extraction and electro-mobility and legitimizing them as critical and green.

While these three drivers make criticality, criticality impacts on strategies of actors that, in turn, also shape how criticality evolves, most importantly producer firms in GPNs and financial actors (through shaping supply, demand, technology, price-setting, etc.). The lithium boom is linked to changing strategies of established producers (chemical companies, miners, refiners) focused on consolidating their power, through integration of upstream processes, but also through strategic agreements with buyers. Buyers or downstream actors (automakers, battery producers) also started entering upstream nodes to secure supply, challenging power relations. Junior miners became more important in exploration projects, following speculative 'high risk-high reward' strategies, and the more volatile and risky market provided more room for international traders. Increased production, however, requires financial actors for equity and debt finance. Equity listings on stock exchanges enable the entry of junior miners which contributed to opening new, often high-risk extractive frontiers. The emergence of green bonds

highlights a potential shift of the sustainability-finance nexus towards resource extraction, which was generally eschewed by ESG criteria, enabling access to more and cheaper funds. These financing relationships, and particularly shareholder interests in lithium producers, have driven a move from fixed to variable benchmark price-setting, while financial actors' interests in direct exposure to lithium price developments have led to the creation of lithium derivative markets. These dynamics have accelerated the risk of boom-bust patterns and short-termism in lithium GPNs, and also support the positions of certain actors such as international trades that can offer price risk management and PRAs that report prices.

But the sustainability-finance nexus has a broader impact in shifting the perception on finance towards being an enabler of sustainability transformations. This is exemplified in 'green' investment stories and policies supporting 'green' finance, which endorse investment (and speculation) that has any link to products and projects defined as 'green', side-lining the destabilizing and destructive impacts of (global) finance. Through the sustainability-finance nexus financial interests and related conflicts of interests with other actors and objectives are overshadowed by the 'joint' goal of green futures. This 'joint' goal renders financial activities crucial to achieving climate goals, while at the same time providing financial actors with green technologies and 'critical' resources as new vehicles for capital accumulation. In this vein, the sustainability-finance nexus is related to the 'finance-extraction-transitions nexus' by Franz/McNelly (forthcoming) that focuses explicitly on finance shaping new forms of extractivism and green energy transitions. Similarly, to Franz/McNelly (forthcoming: 10), we understand financial actors and interests as entangled with, and within, 'physical' actors and GPNs and we "center (on) the financial flows associated with natural resource extraction" and "how extractivism is enabled by finance in the name of transition". But we extend the analysis to how certain ideas of sustainability render financial actors as crucial to the climate crisis solution and how this, in turn, is utilized through various investment products and strategies, expanding the reach of global finance in GPNs.

In the following section, we substantiate our arguments by empirically analyzing the criticality of lithium at five levels – geopolitically – and environmentally-motivated policies; demand, supply and technology; producers and GPN relations; debt and equity financing; and price-setting and derivative markets.

3. The Criticality of Lithium

3.1. Geopolitically- and environmentally-motivated policies

We identify four policy levels through which the criticality of lithium is established that play out in consumer and producer countries, however to different degrees. We elaborate on the example of the EU as a key lithium consumer country and selected examples from lithium producer countries in South America and Africa. On the first level, many countries in the Global North and South have issued policies around sustainability more broadly and mobility in particular. The key policy in the EU is the EU Green Deal (2019) which sets the overarching goal of climate neutrality by 2050 and, regarding transport, aims for a drastically less polluting sector through a combination of measures, including regulations on EVs. In addition, in 2023 the EC proposed increased subsidies and faster approval for 'green' projects, to remain competitive with industrial support programs of China and the US[2]. Other policies focus specifically on mobility such as the EU Sustainable and Smart Mobility Strategy and Action Plan (2020), aiming to increase the uptake of zero-emission vehicles, the EU Clean Vehicles Directive which defines member states targets for public procurement of 'clean vehicles', and particularly the legislative proposal 'Fit for 55' of 2021, which demands that all new cars registered in Europe are zero-emission by 2035 in the EU. In addition to the Global North and

[2] https://www.reuters.com/business/sustainable-business/eu-lay-out-green-industry-plan-counter-us-china-subsidies-2023-02-01/

China, Brazil and Chile are lithium-producing countries which are also committed to proliferation and adoption of zero-emission vehicles through national policies (IEA 2022).

On the second level, there are policies specifically supporting national battery production. In the EU, the Renewed Industry Strategy (2017) underlies the strategic importance of battery investments to remain competitive in low-emission mobility and energy storage, and the Strategic Action Plan for Batteries (2018) sets out measures to support all aspects of the battery value chain. The European Battery Alliance (EBA) fosters an industry-led initiative to establish a full EU battery value chain. This also includes the Important Projects of Common European Interest (IPCEI), which enable access to public funding for companies engaged in battery production. A two-part IPCEI has been implemented to promote battery production: the IPCEI on Batteries (2019) and the IPCEI European Battery Innovation (2021). Regarding recycling, the European Parliament and Council published provisional new regulations which foresee minimum levels of 6 % of lithium from consumer and industry waste needing to be reused in new batteries. Also, lithium-producing countries aim for value addition by supporting the processing of lithium into batteries. Bolivia aimed at state-led vertical integration from extraction to battery production (Bos/Forget 2021), yet the state company YLB recently struck a deal with a Chinese consortium for the development of a large industrial complex, searching for more effective technologies[3]. Argentina also has ambitions for creating capacities for the assembly and manufacture of battery cells and packs (Obaya et al. 2021). In Zambia and DRC, the governments signed a memorandum of understanding – the 'Zambia–DRC Battery Council' – partnering in the production of battery cells starting in 2030. The states are in contact with potential partners, such as Bosch, and are supported by the US government and the African Development Bank[4] (Wang 2022).

On the third level, policies target access to or domestic extraction of raw materials. The EU Raw Materials Initiative focuses on access to raw materials on global markets and EU supply of raw materials as onshoring has grown in importance in the context of production concentration and geopolitical tensions (Küblböck 2013; Riofrancos 2022). Since 2011 the European Commission has also regularly published a list of critical raw materials, which includes lithium alongside 29 other materials since 2020. This is linked to the broader Action Plan on Critical Raw Materials, which also led to the European Raw Materials Alliance (ERMA) for securing access to sustainable raw and battery materials in Europe. The EU co-funded EIT InnoEnergy Acceleration Fund has facilitated investment in the pilot stages of lithium mines in Spain, Germany, Portugal, and the Czech Republic. Producer countries support mineral production through several measures from attracting (foreign) investment to establishing publicly-owned lithium companies. Zimbabwe has recently opened doors for especially Chinese investors, creating special economic zones with various fiscal and trade incentives[5]. It also banned the export of raw lithium-containing ore to increase local value addition[6], but exempting certain companies already producing lithium. In Chile, lithium has been perceived as a strategic state resource as demonstrated by the recent revision of existing contracts with lithium producers, including new extraction quotas, higher royalties and social and environmental criteria, in addition to plans for a National Lithium Company (Dorn/Gundermann 2022). In Argentina, in the context of large FDI inflows, the custom authorities set an official reference price for lithium carbonate exports, with the aim to improve royalties' collection.[7] Also international organizations develop programs targeting mineral producing countries; e.g., the Climate-Smart Mining Initiative of the World Bank aims to create an 'enabling environment' for mining of critical minerals[8].

[3] https://www.theguardian.com/world/2023/jan/25/bolivia-lithium-mining-salt-flats
[4] https://www.state.gov/the-united-states-releases-signed-memorandum-of-understanding-with-the-democratic-republic-of-congo-and-zambia-to-strengthen-electric-vehicle-battery-value-chain/
[5] https://zidainvest.com/sez/
[6] https://www.reuters.com/world/africa/zimbabwe-bans-raw-lithium-exports-curb-artisanal-mining-2022-12-21/
[7] https://www.fastmarkets.com/insights/argentina-sets-reference-price-for-lithium-exports
[8] https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

On the fourth level, several countries are in the process of aligning their financial system with climate, sustainability and clean energy ambitions. The 2015 Paris Agreement calls for finance flows to be consistent with climate goals[9]. In this regard, the European Commission presented legislative proposals on green finance in May 2018, with the key goal of establishing a market for 'European green bonds' (EuGBs) through an EU Green Bond Standard (GBS) (European Commission 2021). However, it remains open if GBS will become mandatory for all green bonds issued in the EU or a voluntary standard as it is still under consideration of the European Parliament (Kelly 2022). The EU taxonomy for sustainable activities underlying the GBS has included the manufacturing of batteries and EVs as sustainable, but the status of mining of critical minerals remains to be clarified (TEG 2020). Industry-driven initiatives are also driving the adoption of sustainable finance such as the Glasgow Financial Alliance for Net Zero (GFANZ) announced at COP26 in 2021[10], which is a coalition of net zero-committed financial institutions and includes most global banks and asset managers.

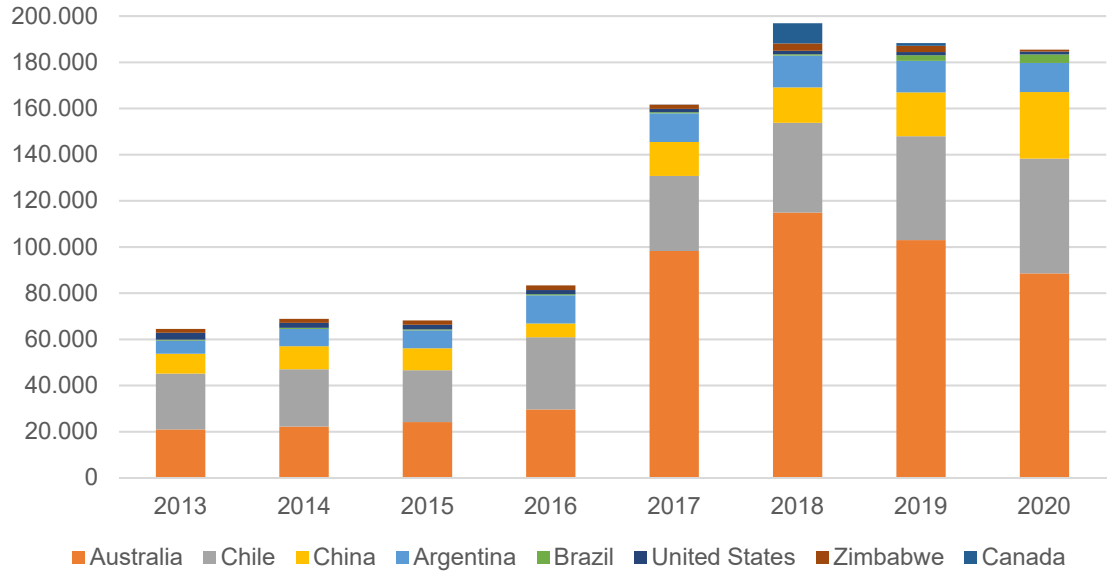
3.2. Demand, supply and technology

Given the short- to mid-term carbon neutrality goals across the globe, lithium demand is forecasted to grow significantly (Home 2022b). An analyst interviewed said: "it's this kind of structural lack that is causing prices to increase that much and (leads to) kind of the scramble for any sort of material, regardless even of its quality or the type of material" On the supply side, global lithium production is concentrated geographically, and also still in terms of number of producers (see below), with 89 % of lithium coming from just three countries in 2020 – Australia, Chile and China. Other key producers include Argentina, Brazil, the USA and Zimbabwe (Reichl/Schatz 2022). But outlooks on a supply gap have led to many new projects and new actors entering the extraction stage. Although not all projects will become operational, the lithium production landscape will change dramatically in the near future.

As depicted in Figure 2, since 2017 lithium extraction has grown rapidly largely driven by expansion of production in established locations. In 2022, approximately 25 lithium mines/salt brines were operational, while an estimated 104 projects were planned or under development (Fitch Solutions 2022). Almost two thirds of these new projects are based in locations which already produce lithium, most prominently Canada, Argentina, USA and Australia. Australia will likely remain the largest producer, but once projects in Canada, Argentina and USA succeed, their importance in the global market may increase significantly. As shown in Table 1, 16 new countries are now likely to also become lithium-producing countries, in addition to the eight indicated in Figure 2. Some of the projects, e.g., in Germany and Mexico, focus on new extraction technologies and are therefore uncertain; other projects are risky because they take place in jurisdictions with unstable domestic situations, e.g., DRC and Mali. Projects have also been contested by local communities, e.g., in Portugal and Serbia, which led to delays and, in the case of the project in Serbia, revoking of the mining license.

[9] https://www.wri.org/blog/2018/12/aligning-!nance-forgotten-goal-paris- agreement-it-vital-successful-climate-action
[10] https://www.gfanzero.com

Figure 2: World production of lithium



Notes: Lithium reported as lithium oxide (Li_2O) content; in metric tons; Bolivia, Nigeria, Namibia and Portugal have been reported to produce marginal volumes of lithium, yet not at commercial scale and hence they are not included in the figure.

Source: Reichl/Schatz 2022

Table 1: Active and new projects in 2022

Number of active and new projects in 2022	Country
over 25 projects	**Canada**
15-20 projects	**Argentina**
	Australia
	United States
10-15 projects	**China**
5-10 projects	**Chile**
2-5 projects	**Brazil**
	Germany
	Mali
	Mexico
	Portugal
	Serbia (license revoked)
	Spain
	Zimbabwe
1 project	Austria
	Bolivia
	Czech Republic
	DRC
	Finland
	Ghana
	Ireland
	Namibia
	Peru
	United Kingdom

Note: Countries with active projects in bold font. New projects include projects at varying stages of development, including in exploration.

Source: Own complication on the basis of Fitch Solutions (2022).

Predicting lithium's future supply (in terms of volumes) and demand (in terms of both volumes and specifications) is even more difficult linked to ongoing technological developments that might lead to shifting to other minerals or demanding specific specifications of lithium. Currently, the lithium boom is taking place over volumes of lithium, with other considerations

such as the grade of lithium, the specific type and the way of extraction being secondary. These factors will likely become crucial, which will concurrently influence the criticality of lithium and stimulate changes in power relations between actors and geographical locations in lithium GPNs. Technological developments are central at three levels – the extraction stage, battery technology and recycling.

Today, there are two main ways of extracting lithium. In South America's 'lithium triangle' (Argentina, Bolivia, Chile), lithium is largely extracted from brines (through evaporation processes) which takes longer but is cheaper, whereas in Australia, Brazil and Zimbabwe lithium bearing ores (such as spodumene) are mined. China and the US are the only countries that produce lithium from both brines and ores. New extractive technologies like direct-lithium-extraction (DLE) or new sources of producing lithium like extracting lithium from clay or from seawater are likely to influence lithium supply. DLE technologies use special filters to recover lithium at higher rates from brines with a lower use of freshwater, reducing the overall time needed for extraction. Clay extraction has recently received a lot of attention, because it is not as geographically concentrated. It is argued to pair the benefits of mining (shorter extraction time) and brine extraction (cheaper than mining). Moreover, extracting lithium from seawater may become more important due to wide availability, and a cost-efficient and more easy process of extraction (Lenntech 2022).

Also new battery technologies have important impacts on how much and what specifications of lithium are demanded, influencing future demand and supply scenarios. Currently nickel-manganese-cobalt (NMC) batteries are dominating the market together with lithium-iron-phosphate (LFP) battery technologies[11]. Their main differences lie in their composition of different minerals and the lithium's type and share in the actual battery pack (LaRocca 2020: 23). At the same time, new technologies like solid-state batteries, which use sodium in place of lithium are being adopted by producers as alternative chemistries, but also other lithium-based batteries, such as lithium-sulfur and lithium-air batteries may disrupt the market (Bajolle et al. 2022). It is difficult to forecast the development of battery technologies, yet these developments have an impact on the quantity and type of lithium demanded and its criticality.

Regarding recycling, even though currently only a small percent of batteries is recycled, in 2030 lithium from secondary sources is suggested to constitute 6 % of total lithium production[12]. Currently, recycling is still regarded as costly (Greim et al. 2020: 3). This is also linked to the great diversity in materials used to produce batteries for EV, which leads to difficulties in creating a universal recycling technology that is cheap and technically feasible (Greim et al. 2020; Huang et al. 2018). At the same time, new technologies enable recycling 80 % of an old li-ion battery (Fortum 2023). Should the regulations on recycling requirements discussed above for the EU be implemented, production costs of batteries and EVs could increase rapidly and/or may require a shift to recycled lithium. One expert even assessed recycling's role in future supply as follows: "[r]ecycling will become very important. So, it could be that fifteen years from now, you will not need to develop additional lithium mines... prices at that time should go down. So, you have the possibility to capture value that you are producing now and over the next 15 years. If you are not there, you better not go to the party."

3.3. Producers and GPN relations

Lithium mineral producing (i.e., mining and extracting) firms are mostly international chemical companies and control market operations in the upstream part. In 2017, only four companies (Talison, SQM, Albemarle, and FMC (now Livent)) dominated the lithium market by controlling the majority of global lithium production and, until recently, the market has been described as oligopolistic. But this landscape is changing as both established mining and refining companies active in other sectors, international traders and junior miners as well as automakers and

[11] Nickel-cobalt-aluminum (NCA) batteries are also used but less frequently and currently only by Tesla.

[12] https://www.mckinsey.com/industries/metals-and-mining/our-insights/lithium-mining-how-new-production-technologies-could-fuel-the-global-ev-revolution

battery producers have entered the lithium market (Azevedo et al. 2018; Barandiarán 2019; Sterba et al. 2019). Table A1 in the appendix shows the type of engagement and expansion in lithium production of selected producers.

Today, the largest lithium producers are the chemical company SQM (Chile), refiner Tianqi (China), chemical company Albemarle (US), refiner Ganfeng (China), chemical company Livent (US), and spodumene producer Pilbara (Australia). Lithium producers also often integrate downstream capacities; an example is Livent which largely extracts lithium in Argentina, but also owns plants producing battery-grade lithium hydroxide in the US and China (Bridge/Faigen 2022). Prominently, Ganfeng is pursuing a strategy of full integration from lithium extraction to battery manufacturing and battery recycling, as well as production of a wide array of lithium specifications, for which it was dubbed a 'lithium supermarket'. The expansion of lithium production after 2017 (Figure 2) has been largely driven by these major actors. Beyond expanding existing capacities in Australia, Chile and China, these major companies also focus on investing in new projects in Canada and Argentina, among others (Table A1).

However, the 129 active and prospect operations indicated in Table 1 are held by 105 firms, from which 87 control (defined as minimum of 50 % ownership) only a single project (Fitch Solutions 2022). Many of these firms can be classified as 'junior' producers, which are small firms looking for new lithium sources. As successfully developed mining projects are generally sold to major mining companies, juniors are not primarily focused on mining, but rather attempt to open up new resource frontiers (Gilbert 2020; Karwowski 2015; Kneas 2020). An example of this strategy is the Arcadia Lithium Mine Project in Zimbabwe by the Australian company Prospect Resources, which sold it to Zhejiang Huayou Cobalt in April 2022 and was able to distribute USD 444 million cash dividends to its shareholders. Other notable projects include Sigma Lithium project in Brazil, Manono project in DRC and the Cinovec project in Czech Republic (Table A1).

Not only mining and refining companies are participating in the lithium boom. Automakers and battery producers have paid higher prices for lithium inputs and struggled to secure supplies and hence have been investing into upstream activities, with automakers extending earlier vertical integration in the battery segment to mines (Home 2022a). The involvement of automakers and battery producers takes place through joint ventures with mining or refining companies (e.g., BYD), off-take contracts with refining companies (e.g., BMW, Tesla), or equity or large-scale debt financing of new projects (e.g., General Motors and Stellantis) (Table A1). Key global battery producers pursue similar strategies: LG Energy Solutions holds equity in lithium refining companies, as well as offtakes with both established and junior producers, while companies such as CATL and SVolt and EVE invested directly into extraction projects.

Less pronounced than battery producers and automakers, international traders also become increasingly active in the lithium market, such as Traxys, Glencore and Trafigura[13]. This underscores an important change in the market, as traditionally lithium markets operated without intermediaries; with the exception of the Chinese domestic market. Increased demand paired with a move towards variable, short-term price-setting in contracts have created opportunities for traders, which make profits by connecting different actors along supply chains and taking on associated price (and other) risks. However, their activities have not been limited to intermediation, as they also attempt to gain influence in lithium supply through stockpiling but also processing investments (Fastmarkets 2022). For example, in May 2022 Trafigura announced equity investment in Green Lithium, which is planning the development of one of the first commercial lithium refineries in Europe.

Many of the projects in Table A1 and particularly projects of junior miners are expected to not materialize as predicted. One lithium market analyst argued for the case of new projects in Zimbabwe and DRC: "I don't think the Zimbabwe project is going to be producing by 2025. I don't think the DRC project is going to be producing by 2025. I don't say that they never are

[13] https://www.mining.com/web/the-lithium-market-is-hotter-than-ever-and-traders-are-moving-in/

going to produce, but I don't think they will be on time to produce. Because simply there is no time to get there". This is related to the long-term nature and related uncertainties in terms of budget issues, delays and actual quantity and quality of resources coming with new mining projects. It can take up to twenty years to start mining, due to the different stages projects have to go through like resource discovery, feasibility studies and constructing extraction and production sites (Greim et al. 2020). According to expert interviews, particularly for the lithium industry, there is also still limited know-how available (both in terms of expertise and technologies), since the industry has boomed for less than a decade. These factors can act as bottlenecks in establishing new productive assets and underscore the ongoing lithium boom. Many new projects are not based on long-term considerations, rather they aim to tap into high demand and prices in the short-term, but they may not prove economic with increasing supply and potentially changing technologies.

3.4. Debt and equity financing

Financial actors are essential to finance the capital-intensive expansion of lithium extraction, typically through equity, bank loans and other debt instruments (Adams 2019). While many activities around electro-mobility such as EV manufacturing and battery production are classified as suitable for ESG considerations, similar to other mining activities lithium extraction and processing has generally been excluded (Petavratzi et al. 2022). However, the criticality of lithium in the context of sustainability transformations is opening up better financing conditions particularly through green bonds – debt securities issued to raise capital to support climate related or environmental projects (Jones et al. 2020). The first green bond was issued by the World Bank in 2008 and since then the green bond market has accelerated rapidly, with cumulative investments of USD 1 trillion in 2022 compared to USD 100 billion in 2017 (EY 2022; Grzegorczyk/Wolff 2022). The high demand for green bonds indicates the increasing importance of ESG-compliant investments, for which investors accept an interest rate discount (i.e., pay a green premium, called 'greenium'), thereby offering more favorable lending conditions to green projects (Wass 2021).

The mining and metals sector has played a subordinate role in the green bonds market so far capturing little more than 1 % of green bonds volumes (EY 2022). Selected mining companies raised funds through green bonds for energy efficiency, clean transport or renewable energy projects, but usually not for mining activities[14]. However, the lithium producers SQM and Livent have issued green bonds to explicitly finance development, operation and expansion of lithium extraction; SQM raised USD 700 million out of their USD 2.7 billion total debt and Livent USD 238 million, which is its only outstanding bond (Livent 2022; SQM 2021). SQM referred to clean transportation and energy efficiency as their lithium extraction and processing is primarily for EV batteries and energy storage (ebd.). Hence, the 'greenness' of lithium-based technologies is conflated with criticality. Stating that lithium extraction is a necessity for clean transportation and energy efficiency represents lithium production as green by default rather than focusing on the actual activities of lithium producers.

Such green bond issues for lithium extraction are made possible by the lack of mandatory standards for environmentally sustainable projects and hence green bonds (Jones et al. 2020; Wooldridge 2022). Firms usually refer to voluntary standards (e.g., the Climate Bond Standard or the Green Bond Principles, established by a consortium of banks). It is the sheer process and methodology of evaluation of the 'greenness' that creates the surplus value or 'greenium' of green bonds (Bigger 2017; Christophers 2019) without assuring or monitoring the actual environmental impacts, creating the risk of environmental non-performance, also called 'green default' (Talbot 2017). In this vein, SQM states: "No assurance can be given that any goal or plan set forth in forward-looking statements in this [Green Bond Financing] Framework can or

[14] https://www.mining.com/web/fortescue-makes-foray-into-green-bond-market/

will be achieved, and readers are cautioned not to place undue reliance on such statements […]" (SQM 2021: 12).

Selected lithium producers have also used further opportunities to benefit from growth of ESG-based investment funds (Belloni et al. 2020). Several major lithium producers are classified as chemical companies that receive better ESG ratings than other mining companies and junior lithium producers. For instance, Albemarle, Livent and SQM are rated with a medium ESG risk compared to high or severe risk for other mining companies[15], and are, for instance, constituents of the MSCI Future Mobility ESG Filtered Index. This is used as a basis for 'green' investments by funds, enabling access to sustainability-motivated equity capital.

The other major source of capital for lithium producers is equity. Even though the dominant US and Chinese lithium producers are usually listed companies, this way of raising capital is particularly important for junior lithium producers. In contrast to larger mining companies, these smaller firms have only limited access to bank loans and debt capital markets, as they lack regular cash flow from mining operations (Tilton/Guzmán 2016). Rather, junior lithium producers seek high-risk financial capital from equity markets, as their performance depends on risky processes of exploring and developing new mining projects as well as changes in commodity prices.

The criticality of lithium linked to a sustainable investment story has created expectations among financial actors to profit from the expected lithium shortage, leading to a boom of new listings at stock exchanges of lithium producers that aim to explore and develop new mining sites, particularly junior producers, on the Australian Stock Exchange (ASX) in Sydney and the Toronto Stock Exchange (TSX), which are the top exchanges for mining globally (Nunez-Picado et al. 2022). In 2022, it is estimated that 131 lithium producers and developers were listed on the ASX (Cummins 2022) and 55 on the TSX (Henderson 2022). The lithium boom has also impacted on the secondary market where listed stocks are traded. Investment flows and share prices have followed lithium price dynamics, showing the interest of shareholders to be exposed to (booming) lithium prices.

The lithium price surge in 2020/21 attracted particularly substantial investments by mutual funds, which actively allocate funds of private and institutional investors to stocks, and exchange traded funds (ETFs), which passively invest according to stock indices. For instance, the largest ETF Global X Lithium & Battery, which replicates an index of lithium stocks (Solactive Global Lithium Index), experienced an inflow of USD 3 billion from 2020 to 2022 and had USD 4.6 billion of assets under management in 2022[16]. As a result, mutual funds such as BlackRock, Vanguard or Capital Research & Management Company and ETFs such as Global X Management or VanEck are the major shareholders of Albemarle, Livent and Pilbara, holding 85 to 98 % of their outstanding shares. The majority shareholders of junior miners are typically more mixed including venture capital companies, hedge funds as well as major lithium producers.[17]

The criticality of lithium and its links to green finance, raise expectations by financial actors to benefit from the high demand for and prices of lithium. This enables lithium producers to gain enhanced access to funding through green finance with lower interest rates (large lithium producers) and equity market listings (junior lithium producers). In particular, the strong speculative inflows to equity markets increase the risk for a lithium mining boom (and bust) driven by recent price surges and financial actor investment interests. This engagement by financial actors however introduces a focus on shareholder value maximization which aims to increase short-term profits, including through variable and short-term price-setting to be exposed to price developments.

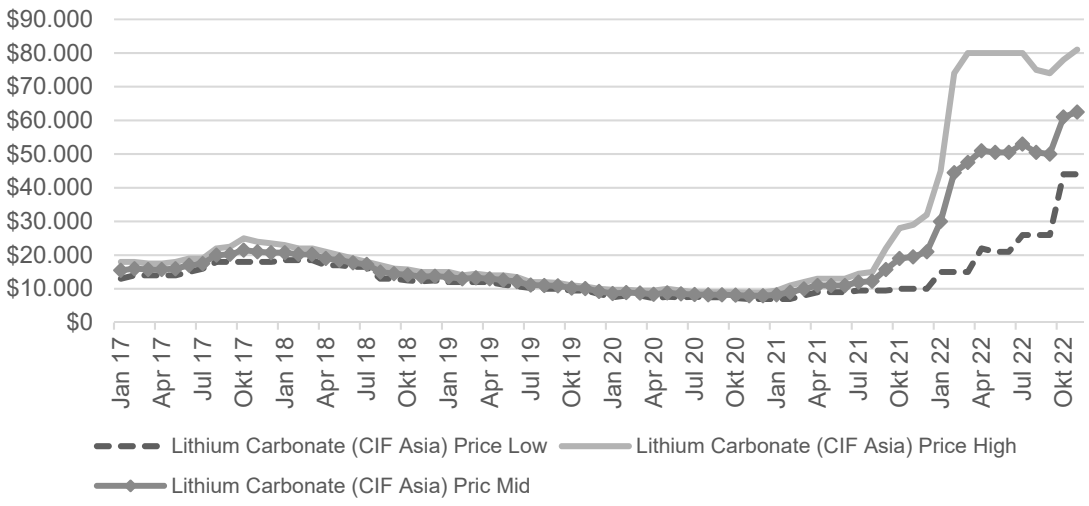
[15] https://www.sustainalytics.com/
[16] www.etf.com
[17] https://money.cnn.com/

3.5. Price-setting and derivative markets

The lithium-boom has been based on rising prices. Figure 3 shows lithium carbonate prices as traded in China, reported by the PRA Benchmark Mineral Intelligence (BMI). Prices increased significantly in 2017 and 2018 as the EV market started expanding. Lithium producers responded, tipping the market into oversupply which led to falling prices in 2020, exacerbated by the COVID-19 pandemic and supply disruptions. Prices surged again in 2021 and 2022, with an all-time high of approximately US Dollar 80,000 per ton for battery grade lithium carbonate in China in October-November 2022, contrasted with ± US Dollar 8,000 per ton just two years earlier. However, while lithium prices are widely referred to, it is difficult to define what the lithium price actually is, as there is not yet a single benchmark that dominates the industry. World prices of commodities typically draw on commodity derivative markets with the three major derivative markets for minerals being LME, Chicago Mercantile Exchange (CME) and Singapore Exchange (SGX). The first two listed lithium contracts in 2021, and the latter in 2022, all referring to the price listings provided by a PRA Fastmarkets.

In the EV-linked history of lithium, we can differentiate between three price-setting periods – long-term, fixed-price contracts, emergence of spot markets, and variable, short-term price contracts linked to benchmarks. Prior to late 2021, the majority of transactions were conducted based on multi-year fixed-price contracts tailored to individual battery-maker specifications, which locked up a large share of battery-grade lithium supply. In these contracts, prices were largely set by lithium producers which also stabilized their revenues. The most common price indexation mechanisms were trade statistics, which reflected the multi-year contract prices in export and import. However, as supply became increasingly squeezed, a lithium spot market emerged, where products are sold for immediate delivery. These changes are reflected in Figure 3 in the growing differential between “Price High” and “Price Low” indicators. As a rule of thumb, the “Price High” line are spot prices and the “Price Low” line are long-term contract prices, showing that producers could get higher prices on the spot markets compared to long-term contracts from 2021. Hence, lithium producers (and recently also international traders) were able to make profits from selling part of their products on the spot market and not only through long-term contracts. There has been a further shift in contracts away from long-term fixed-price towards variable, short-term prices based on benchmarks in contracts. This was driven by lithium price developments and producers (motivated by their shareholders) wanting to gain from high prices and not be locked in fixed price contracts. There is an ongoing struggle around what is to become the lithium world price benchmark used in such contracts with key roles played by PRAs but the role of, and interrelations with, derivative markets are increasing.

Figure 3: Lithium price developments (lithium carbonate)



Note: CIF Asia, USD per metric tonne, monthly data, based on spot prices and prices from contracts lasting up to 12 months.
Source: BMI (2022)

While LME, CME and SGX introduced lithium hydroxide contracts (and SGX also a lithium carbonate contract), currently only CME contracts are traded at very low volumes. The creation of lithium futures responds primarily to the demands of financial investors to gain direct exposure to lithium price developments without holding the physical commodity or shares of firms engaged in physical lithium extraction. As a lithium market analyst interviewed explained: “Basically, the cash-settled lithium contract on the LME – that is not for the battery industry, that is not a usable contract, that's really for investors.” Until recently, industry actors have contested the introduction of lithium futures related to characteristics of lithium that make the creation of derivatives difficult: (i) the difficulty to standardize derivative contracts given the many different specifications with lithium products being more perceived as specialty chemicals and not as a commodity and (ii) the lack of a clear underlying as, given ongoing technological developments, there is no clear choice between hydroxide and carbonate as the most traded product. This quasi-commodity nature of lithium was reflected in earlier long-term contract terms, with specification of lithium meeting particular buyers’ needs. These contracts were also a source of power for established producers giving them discretion over price-setting – “they [large producers] love the market being fragmented and opaque. They can go to Tesla and dictate the terms”. Long-term fixed-price contracts also gave producers security, meaning that they had little interest in derivatives for price-determination nor for price risk management purposes.

Another critique of derivative markets is related to cash-settled futures, which are prevalent as physical-settled futures are not possible[18] due to the non-storability of lithium hydroxide. Cash-settled futures rely on short-term price indicators, which are provided by PRAs. All three derivative exchanges chose Fastmarkets as a provider of lithium prices, reinforcing the role of this PRA in the lithium market. This came as a surprise as when the LME first announced the launch of lithium futures in 2019 another PRA (BMI) was considered to be the market leader. It seems that the decision was made on the basis of Fastmarkets’ methodology, existing relationship for other cash-settled futures, Fastmarkets being a bigger company, but also, and crucially, possibly Fastmarkets ability, or acceptance, to issue a weekly price. The last point has been controversial as the lithium market given that weekly prices may not be adequate, as stated by one critic “[t]hat's just not how the [lithium] market works. These are not liquid spot markets… There were days and probably weeks when things just wouldn't trade. So where is that number coming from? If there is no trading there...what's the trading price?”. This is linked to the general critique of PRA’s price determination methodologies. Methodologies are based on primary price data on actual or potential transactions reported by actors at different stages of GPNs, but details on who was contacted – physical or financial actors for example – and how different quotes are used are not made public. A PRA representative stated that “quantity of data and a diversity of assessments is important so each player on the chain (…) has a say. But really it is the quality of them, how active [they are], what’s their kind of visibility.” Yet, focus on specific ‘quality’ sources can become problematic since this may favor bigger transactions or transactions coming from particular actors. Further, in the case of lithium being characterized by low illiquidity periods, PRAs look not only for spot deals that have taken place and contracts that have been concluded, but also for bids and offers, possible deals, indications and other indicators into account when determining prices.

The strategies of lithium producers, linked to shareholder pressure, changed more recently towards derivative markets. In the context of the price surge starting in 2017 and 2018, producers wanted to benefit from higher prices instead of being locked in long-term fixed-price contracts. With falling prices after 2019 the sentiment also changed related to financing needs. A lithium market commentator said at the time “[t]hey (producers) can’t raise any more money. They can't convince their bankers that there is any certainty over the future price, because there is no futures market. Then they come running to the LME and saying 'actually it would be very nice if the market was a bit more transparent’”. Hence, futures markets were seen as

[18] At maturity, physical-settled futures require the delivery of a physical commodity at warehouses (if contracts are not closed before), while cash-settled futures involve the transfer of cash equal to the difference between spot and futures prices.

necessary to satisfy financing needs as they would allow producers to present more transparent prices to banks and other financial institutions, through the use of a recognized (derivative market-based) benchmarks in contracts as well as for price risk management through hedging on these markets. After the price surge in 2021 and 2022, large lithium producers will likely keep their interest in futures contracts for risk management, given the uncertainties linked to the lithium boom and variable, short-term price-setting in contracts. As interest in derivative contracts increases and markets become liquid, financial actors can also enter these markets bringing in their short-term and speculative trading strategies, often disconnected from fundamentals. This may impact on prices, increasing their volatility as seen for other metals (Gilbert 2018).

4. Conclusions

Criticality legitimizes extractivism for sustainability transformations and is made by articulations of the 'risk of disruption' based on demand, supply and price perceptions, policies linked to green extractivism, and underlying narratives around the role of commodities in development. The lithium boom has led to changing strategies, power relations and the entrance of new actors in lithium production, with an interest to either control supply (mining and refining companies, battery producers, automakers, international traders), develop and resell exploration projects (junior miners), and 'take on' price risks (international traders). Financial actors have contributed to the lithium boom through financing extraction via debt, including green bonds, and equity involvements, shaping producer firm strategies, and through price-determination and-setting, changing to variable short-term price-setting and creating links to derivative markets. In more detail, five impacts are central: (i) equity involvement enabling junior miners to engage in risky explorations opening new extractive frontiers; (ii) higher ESG ratings of chemical (compared to mining) companies allowing more favorable access to equity capital in the context of 'green investment stories'; (iii) financing through poorly regulated green bonds allowing for expansion of extractive activities at lower interest rates ('greenium') not based on actual environmental performance; (iv) shareholder pressure to move away from long-term price-setting to variable short-term prices; and (v) more direct (speculative) investment through creating and expanding the role of derivative markets in price-determination.

While such processes are often referred to 'maturing of the market', they exacerbate risks inherent to commodity production and trading by accelerating boom-bust patterns and short-termism. But, in a 'critical' market with a 'gold rush'-like tendency where being 'on time' to supply booming demand is likely to deliver high profits, risks and uncertainties tend to shift to the background. Financial actors support, or even enable, such a boom linked to the mobilization of sustainable investment stories, which we call the sustainability-finance nexus. In this narrative, the role of financial actors is presented as necessary fur sustainability transformations and 'green growth'. This follows the narrative for commodity extraction in the context of 'green extractivism' and the 'climate change consensus' (Dorn et al. 2022). We problematize this radical change of perception of financial actors which side-lines the short-term and speculative logics and destabilizing and detrimental outcomes of (global) finance, in addition to the problematic outcomes of extraction.

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Appendix

Table A1: Selected lithium producers, types of engagement and access to finance

	Company name (origin)	Main activity	Type of engagement in lithium production	Access to finance
Chemical companies	SQM (Chile)	Chemical company	**Active projects:** ○ Salar de Atacama, Chile - brine extraction ○ Salar del Carmen, close to Antofagasta, Chile - lithium carbonate and lithium hydroxide plant **New projects:** ○ Mt Holland, Australia - lithium mine ○ Kwinana, Australia - refinery (JV - Covalent Lithium, an equally owned JV of Wesfarmers (Australia) and SQM)	○ Listed on Santiago Stock Exchange and NYSE ○ Green bonds to finance production expansion ○ Tianqui as a major shareholder - 23.8 %
	Albemarle (US)	Chemical company	**Active projects:** ○ Salar de Atacama, Chile - brine extraction ○ La Negra, Chile - lithium carbonate plant ○ Silver Peak, US - brine extraction ○ Greenbushes, Australia - lithium mine (JV Talison Lithium Pty Ltd: Tianqi Lithium Corporation / IGO Limited JV (51 %) and Albemarle Corporation (49 %)) **New projects:** ○ Kemerton, Australia - lithium hydroxide plant ○ Wodgina, Australia - lithium mine ○ Both JV - Albemarle 60 % and Mineral Resources (Australia) 40%	Listed on New York Stock Exchange (NYSE)

	Livent (earlier FMC, US)	Chemical company	**Active projects:** ○ Salar del Hombre Muerto, Argentina - brine extraction ○ Bessemer City, US and Rugao, China - lithium hydroxide plant **New projects:** ○ Nemaska, Canada - integrated lithium hydroxide operation (Equally-owned joint venture with Investissement Québec)	○ Listed on NYSE ○ Green bonds for the development, operation and maintenance of Livent's assets dedicated to the future extraction of lithium and production of lithium carbonate and hydroxide
	Zhejiang Huayou Cobalt (China)	Battery chemical material manufacturer	**New projects:** ○ Arcadia Lithium Mine, Zimbabwe - lithium mine (fully owned) ○ Purchased Project in Zimbabwe from the Australian company Prospect Resources (junior miner)	Listed on Shanghai Stock Exchange
Mining companies	Pilbara (Australia)	Spodumene mining	**Active projects:** ○ Pilgangoora Project - Australia - lithium mine (together with Ganfeng as an equity partner and off-taker (10+5+5 year deal)) **New projects:** ○ Mt Francisco, Australia - lithium mine (JV, 70 % Pilbara, 30 % Atlas Iron Limited)	○ Listed on ASX ○ Great Wall holds shares in Pilbara
	European Metals Holdings (Australia)	Junior mining company	**New projects:** ○ Cinovec, Czech Republic - lithium mine (joint venture with the energy company CEZ a.s.)	Listed on ASX and AIM
	Sigma Lithium (Canada)	Junior mining company	**New projects:** ○ Sigma Lithium, Brazil - lithium mine	Listed on TSX and NASDAQ
	Lithium Americas (US)	Junior mining company	**New projects:** ○ Cauchari-Olaroz, Argentina - brine extraction (joint venture between Lithium Americas (44.8 %), Ganfeng Lithium (46.7 %) and JEMSE Jujuy Energía y Minería Sociedad Del Estado (8.5 %)) ○ Pastos Grandes, Argentina - brine extraction (fully owned) ○ Thacker Pass, US - lithium mine (fully owned)	Listed on TSX and NYSE

	Sinomine Resource Group (China)	Mining (various)	**Active projects:** ○ Bikita, Zimbabwe - lithium mining (fully-owned)	Listed on Shenzhen Stock Exchange
	Rio Tinto (UK)	Mining (various)	**New projects:** ○ Boron, US - lithium mining from tailings (demonstration plant) ○ Rincon, Argentina - brine extraction ○ Jadar, Serbia - lithium mining (licence revoked) Rio Tinto holds a $10 million strategic equity investment in Nano One (Canada), a technology company with a patented industrial process to produce low-cost, high-performance cathode used in lithium-ion batteries.	Listed on ASX
Refining companies	Tianqi Lithium Corp (China)	Refining	**Active projects:** ○ Greenbushes, Australia - lithium mine (Talison, owned by Joint ventures partners Tianqi Lithium Corporation / IGO Limited JV (51 %) and Albemarle Corporation (49 %)) ○ Kwinana, Australia - lithium refining (operated by Tianqi Lithium Energy Australia Pty Ltd (TLEA))	Listed on Shenzhen Stock Exchange
	Ganfeng Lithium Group (China)	Refining	**Active projects:** ○ Ningdu Heyuan, China - lithium mine ○ Yilping Qinghai, China - brine extraction (49 % Ganfeng, 51 % China Minmetals) **New projects:** ○ Sonora Lithium, Mexico - clay (Ganfeng 22,5 %, 77,5 % Bacanora) ○ Mt Marion, Australia - lithium mining (50 % Ganfeng, 50 % Mineral Resources) ○ Mariana, Argentina - brine extraction (90 % owned via a JV via International Lithium Corp) ○ Avalonia, Ireland - lithium mine ○ (55 % owned, earn-in option to acquire another 24 %, JV with International Lithium Corp.) ○ Cauchari-Olaroz, Argentina - brine extraction (Lithium Americas (44.8 %), Ganfeng Lithium (46.7 %) and JEMSE Jujuy Energía y Minería Sociedad Del Estado (8.5 %)) ○ Sal de la Puna, Argentina - brine project (35 % Ganfeng, JV with Arena Minerals) ○ Goulamina, Mali - lithium mine (50 % Ganfeng, 50 % Leo Lithium)	Listed on Shenzhen Stock Exchange and Hong Kong Stock Exchange

	Chengxin (China)	Refining	**Active projects:** ○ Huirong mining, China - lithium mine (Chengxin holds 25.18 % equity) **New projects:** ○ Sabi star, Zimbabwe - lithium mine ○ Yelonggou, China - lithium mine	Listed on Shenzhen Stock Exchange
Battery producers	CATL (China)	Cell and battery manufacturer (Tier 1[19])	**New projects:** ○ Manono, DRC - lithium mining (financing agreement with a junior miner AVZ (Australia) via subsidiary CATH) ○ Yibin, China - lithium hydroxide plant - joint venture with Suzhou (China)	
	LG Energy Solutions / LG Chem (South Korea)	Cell and battery manufacturer (Tier 1)	LG Energy Solutions owns an 8.75 % stake in China's Tianqi Lithium Off-take agreements with SQM, Ganfeng, Sigma	
	EVE (China)	Cell and battery manufacturer (Tier 2)	**New projects:** ○ China - lithium hydroxide and carbonate plant - JV (80 % EVE, 20 % Jinkunlun) ○ Xinghua Lithium, China - lithium carbonate plant (49 % EVE stake)	
	SVolt (China)	Cell and battery manufacturer (Tier 2)	**New projects**: ○ Mt Alexander, Australia - lithium mine (Memorandum of Understanding between St George Mining (Australia) and SVOLT)	
	SKI (South Korea)	Cell and battery manufacturer (Tier 1)	Off-take with Lake Resources (Australia) on approx. 50 % of Kachi project (Argentina) production	

[19] PRA BMI classifies battery producers into three tiers: "Tier 1- Qualified to supply multi-national electric vehicle (EV) producers outside of China; Tier 2 – Qualified to supply Chinese EV market/non-EV applications; Tier 3 – Unqualified – limited or no track record of cell production" (Source: https://www.benchmarkminerals.com/the-three-tiers-of-battery-megafactories/)

Automotive OEMs	Stellantis (France)	Automaker	Off-take agreement with and the second largest shareholder in Vulcan Energy (Germany) 10 year off-take agreement on hydroxide with Controlled Thermal Resources (US).	
	BYD (China)	Automaker and cell and battery manufacturer (Tier 1)	**Active projects:** o Qinghai Salt Lake, China - brine extraction (JV BYD and Qinghai Salt Lake) o Zhabuye, Tibet - brine extraction (Tianqi and BYD)	
	General Motors (US)	Automaker	Off-take agreement with Livent **New projects:** o Investment in Controlled Thermal Resources (US) (Salton Sea Geothermal Field)	
	BMW Group (Germany)	Automaker	Off-take agreement with Ganfeng, European Lithium (Austria)	
	Ford (US)	Automaker	Off-take agreement with Lake Resources, Liontown Resources (Australia)	
	Volkswagen (Germany)	Automaker	Off-take agreement with Ganfeng	
	Toyota (Japan)	Automaker	JVs with Allkem (Australia): **Active projects**: o Olaroz, Argentina - brine extraction (27.32 %) **New projects:** o Naraha, Japan - conversion plant (carbonate to hydroxide) (25 %) Toyota also owns 6.2 % shares of Allkem	
	Tesla (US)	Automaker	Offtake with Ganfeng, Piedmont Lithium (US) and Liontown Resources (Australia) **New projects:** o Robstown, US - lithium refining	

International traders	Trafigura (Switzerland)	Commodity Trading House	**New projects:** ○ Green Lithium (UK) - lithium refining (equity investment)	
	Glencore (Switzerland)	Commodity Trading House	Strategic partnership with a Li-Cycle, a lithium-ion battery recycler in North America (approximate 10 % equity stake in Li-Cycle)	
	Traxys (Switzerland)	Commodity Trading House	Off-take agreement with Li-cycle Feedstock supply to Tees Valley Lithium (UK, lithium refining)	

Sources: SQM (sqm.com/en/producto/carbonato-de-litio/#:~:text=SQM%20produces%20lithium%20carbonate%20in,from%20the%20Salar%20de%20Atacama.); Albermale (https://www.albemarle.com/locations; https://www.talisonlithium.com/ ; https://www.albemarle.com/western-australia) ; Livent (https://livent.com/company-overview/global-locations/ ;https://ir.livent.com/news/news-details/2022/Livent-Announces-Agreement-to-Double-its-Ownership-Stake-in-Nemaska-Lithium-to-50-Percent/default.aspx); Huayou Cobalt (https://www.reuters.com/business/chinas-huayou-buys-lithium-mine-zimbabwe-422-mln-2021-12-22/) ; Pilbara (https://www.pilbaraminerals.com.au/our-company/our-projects/) ; European Metals Holdings (https://www.europeanmet.com/cinovec-project-overview/); Sigma Lithium (https://www.sigmalithiumresources.com/project/); Lithium Americas (https://www.lithiumamericas.com/); Sinomine (https://www.reuters.com/article/sinomine-zimbabwe-lithium-idUKL8N2Y43HA) ; Rio Tinto (https://www.riotinto.com/products/lithium) ; Tianqi (https://www.tianqilithium.com.au/site/pdf/e3d259ad-6e9f-4eb0-96e5-3911c1f8f0b9/Tianqi-Lithium-Energy-Australia-Produces-Australias-First-Battery-Grade-Lithium-Hydroxide.pdf) ; Ganfeng (http://www.ganfenglithium.com/about3_en.html); Chengxin (https://en.cxlithium.com/product/7/); CATL (https://www.mining-technology.com/news/avz-manono-project-drc/; https://allafrica.com/stories/202207120008.html#:~:text=Suzhou%20supplies%20lithium%20and%20owns,the%20world%27s%20lithium%2Dion%20batteries); LG Energy Solutions (https://www.electrive.com/2021/01/11/lg-energy-solutions-sources-lithium-from-sqm/; https://www.prnewswire.com/news-releases/sigma-lithium-and-lg-energy-solution-sign-milestone-six-year-binding-term-sheet-for-lithium-offtake-agreement-301392472.html; https://www.fastmarkets.com/insights/ganfeng-lithium-signs-new-contracts-with-lg-chem-tesla) ; EVE (https://stock.finance.sina.com.cn/stock/go.php/vReport_Show/kind/search/rptid/708710340762/index.phtml; https://www.kallanish.com/en/news/power-materials/market-reports/article-details/lithium-eve-takes-49percent-of-tsaidam-xinghua-lithium-0122/) ; SVolt (https://www.globalminingreview.com/mining/14122022/st-george-and-svolt-to-collaborate-on-lithium-projects/); SKI (https://lakeresources.com.au/wp-content/uploads/2022/10/lke_sk-on_12-oct-22.pdf); Stellantis (https://www.stellantis.com/en/news/press-releases/2022/june/stellantis-expands-relationship-with-vulcan-energy-becoming-shareholder-in-decarbonized-lithium-company ; https://www.stellantis.com/en/news/press-releases/2022/june/stellantis-secures-low-emissions-lithium-supply-for-north-american-electric-vehicle-production-from-controlled-thermal-resources); BYD (https://www.chinadaily.com.cn/business/2016-06/23/content_25822497.htm; https://www.autonews.com/china/byd-buys-stake-tibetan-lithium-mining-company); General Motors (https://ir.livent.com/news/news-details/2022/General-Motors-and-Livent-Enter-Long-Term-Lithium-Hydroxide-Supply-Agreement/default.aspx ; https://www.theverge.com/2021/7/2/22559718/gm-lithium-ctr-ev-battery-investment-salton-sea); BMW Group (https://www.greencarcongress.com/2022/12/20221221-euroli.html; https://www.press.bmwgroup.com/global/article/detail/T0303684EN/securing-raw-material-supplies-for-battery-cells:-bmw-group-signs-supply-contract-with-ganfeng-for-sustainable-lithium-from-mines-in-australia?language=en); Ford (https://lakeresources.com.au/wp-content/uploads/2022/04/lke_ford_11-apr-22.pdf; https://www.greencarcongress.com/2022/07/20220701-fordliontown.html) ; Volkswagen (https://www.vwpress.co.uk/en-gb/releases/3721); Toyota (https://www.allkem.co/projects); Tesla (https://www.reuters.com/business/autos-transportation/chinas-ganfeng-lithium-inks-lithium-battery-supply-contract-with-tesla-2021-11-01/ ; https://www.proactiveinvestors.co.uk/companies/news/1002337/piedmont-lithium-amends-tesla-offtake-agreement-will-supply-spodumene-concentrate-from-north-american-lithium-1002337.html; https://www.mining.com/tesla-secures-5-year-lithium-supply-from-liontown/); Trafigura (https://www.trafigura.com/press-releases/green-lithium-and-trafigura-agree-terms-on-a-strategic-supply-chain-relationship-and-equity-investment/) ; Glencore (https://www.glencore.com/media-and-insights/news/glencore-and-li-cycle-announce-innovative-partnership-to-advance-circularity-in-battery-raw-material-supply-chains); Traxys (https://www.greencarcongress.com/2022/04/20220422-lglicycle.html ; https://www.business-live.co.uk/manufacturing/tees-valley-lithium-secures-supply-24547742).