THE CHALLENGE TO DEVELOP THE LITHIUM INDUSTRY IN THE WORLD'S BIGGEST LITHIUM DEPOSIT – A ROADMAP FOR THE TRIANGLE COUNTRIES

by
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A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science in Energy Policy and Climate

Baltimore, Maryland
December 2020

Abstract

This paper addresses the challenge that the lithium triangle countries have to add value to the lithium chain. Despite having the largest global lithium reserves and medium levels of development, Chile, Argentina and Bolivia are only exporters of raw materials. The work focused on two approaches: to consolidate the triangle countries as lead producers of raw material, and to develop strategies to add value to lithium production. For this, a vast array of material from different sources was collated and analyzed approaching different angles of the lithium industry and its Global Value Chain. With regards to the challenge to consolidate the triangle countries as leading raw material producers, these countries must improve water use in the brines' fragile ecosystems and include the affected populations in the generation of wealth from lithium mining. The challenge to add value to the lithium chain is more complex. In this context, the triangle countries should create synergies to define policies and strategies and pursue partnerships with other countries in the region to advance lithium's industrialization to produce LIB and even EVs in South America.

Mentor: Peter Saundry

Acknowledgements

Here I present extend heartfelt acknowledgements to my mentor of this Capstone Project, Dr. Peter Saundry, as he keeps providing invaluable comments and advices on both the structure and content details of this article from start to end.

I also want to appreciate Dr. Daniel Zachary who organize the EPC Capstone Project in this semester thus I have the opportunity to finish this article.

And many thanks to my instructors and classmates who provide me quite amount of inspiration and help in all courses I have attended during my EPC study.

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Introduction

At a time when humanity is undergoing major transformation in the world's energy matrix, lithium has gained great importance in energy transition. Long-term access to lithium chemicals is essential for the global battery industry that supports the expansion of electric vehicles (EVs) and energy storage from renewables. Lithium-ion batteries' (LIB) drive the world's largest and fastest-growing lithium use today. The transition to electric vehicles and renewable energies requires a considerable expansion of battery availability and storage capacity.

Lithium chemicals, especially lithium carbonate and lithium hydroxide, are the raw materials needed to create cathodes because they have a high energy density, allowing more energy to be stored. The so-called triangle countries (TCs) composed of Argentina, Chile, and Bolivia make up about half of the planet's lithium deposits (USGS, 2020). They compete with Australia for leadership of lithium exports, predominantly to the Asian market.

The purpose of this work is to propose strategies to develop the lithium industry in the triangle countries (TCs) based on these two approaches: to consolidate their leadership as exporters of lithium concentrate and to add value to this wealth.

To this end, the work has been divided into four parts. The first chapter provides primary data about lithium resources and its production, and sheds light on the mining sector that plays an essential role in the lithium upstream sector. The second chapter discusses the lithium market to understand the lithium Global Value Chain (GVC) and the challenges that the triangle countries face to add value to their production. By analyzing

this oligopolistic market, it is possible to infer that China, South Korea, and Japan could be called the "triangle countries of lithium-ion batteries" or the holders of the lion's share within the lithium GVC. The third chapter discusses policies and determinants that have contributed to participation in the global market. Finally, the fourth chapter analyzes the challenges for the triangle countries to consolidate leadership in the supply of raw materials and to add value to their production.

After that, this work presents some suggestions and recommendations for the triangle countries. Aware that there is no single answer, the objective is to draw attention to some policies and strategies that any government, and even companies, should consider, to be successful in the Global Value Chain. The belief is that it is possible to overcome obstacles so that the countries in the triangle can benefit from this wealth and generate more development for the region.

Methodology

In order to carry out this work, an extensive bibliographic analysis was carried out to indentify all relevant information to properly contextualize the triangle countries within the lithium industry. As well as focusing on the upstream supply chain, the extraction of raw material by mineral processing through to its transformation into Lithium-Ion Battery, other aspects were also analyzed to present a global picture of the lithium industry. In particular, the characteristics and the strategies of lithium trade required to be a successful player in this emergent market. Finally, with the result of this survey, it was possible to shed light on the triangle countries' strategies.

In this sense, each chapter works as part of a system to explain the whole. Thus, each chapter has its bibliography and independent data collection. For chapter A, the paper relied on data from the US Geological Survey to show lithium reserve and production values, in addition to data from the Fraser Institute to compare mining in the triangle countries with other countries. For chapter B, the work was supported by Professor LaRocca's detailed survey that shed light on the Global Value Chain lithium and several publications to estimate lithium's future consumption. Chapter C uses the didactic material from the World Development Report for 2020 to explain the determinant for success in the global market, also with the support of several publications to show the policies of the key countries in the lithium chain. Finally, Chapter D is dedicated to the countries of the triangle to establish the factors that hinder a better insertion of these countries in the global lithium chain. For this, four publications were essential, the survey by Cochilco (a research body that advises the Chilean government), the work of López which is dedicated to the question of lithium in Argentina, the EV data from the International Energy Agency and Rietmann and Lieven's paper showing the correlation between policies and EV production.

Background

This paper aims to evaluate strategies and policies to improve the lithium industry in TCs (triangle countries). In this sense, qualitative analysis plays a more important role than quantitative analysis. The investigation was made based on an extensive survey of publications from different sources and data from different institutions at distinct stages of the lithium chain.

In order to organize this work, each chapter addressed different aspects. The first covered the upstream sector, with data on resources and production and presenting relevant aspects of the

mining sector that play a key role. The second showed data about the global lithium trade, analyzing each country's role in the Global Value Chain. The third discussed the policies and strategies of some leading countries, and the last chapter introduced the challenges of the triangle countries to succeed in the lithium chain.

From the data collected by these chapters, it was possible to make recommendations for the triangle countries. In this sense, the current paper's merit is not to offer new data or statistical analysis on the topic, but from a vast collection of knowledge, to seek new answers for old problems.

A- Lithium Background

This chapter's objective is to provide basic data about the lithium industry and the triangle countries' mining sector. By shedding light on the size and location of these giants' lithium deposits in Argentina, Bolivia and Chile, it will be possible to understand why they are known as the lithium triangle countries. Another important factor is to discuss the ability to attract investment to the lithium mining sector. If the triangle countries want to add value for their lithium industry, they need first to consolidate leadership in the upstream sector.

1- Lithium Reserves

As shown in the figure below lithium brine deposits in Latin America are located between Argentina, Bolivia and Chile in the area known as the "Lithium Triangle."

Figure 1: Lithium Triangle Countries from "The Economist", 2017.

In general, lithium reserves are mainly associated with two distinct geological contexts, the pegmatite rocks and the brines (also known as salt flats) that determine the type of mining activity and the environmental impact caused by the extraction of the mineral. Brines are associated with evaporite sedimentary rocks where lithium is dissolved in water, and nature (evaporation) plays an essential role in mineral concentration. On the other hand, the pegmatites (the geological context in which Australia is the largest lithium producer) are igneous rocks characterized by rocky massifs. According to data

from the United States Geological Survey (USGS), brine deposits represent about 60% of the lithium globally, while pegmatites represent about 25%.

Regarding the use of lithium, according to USGS data, approximately half of lithium's current production is used for the production of batteries and the remainder for the production of glass, ceramics, lubricants, and pharmaceuticals, among others. The strong demand for lithium batteries in the market is due to their characteristics: light, high energy density and high recharge capacity.

There is a predominance of the triangle countries regarding these resources, which make up approximately 45% of the global resources. According to USGS's latest lithium report (table below), Bolivia has the world's largest known lithium resources. Bolivia's 21 million tons of lithium is credited to only the Uyuni salt flats. It does not include the currently unquantified lithium resources present in Bolivia's Coipasa and Pastos Grandes brines. Alone, Uyuni has three times the lithium resources of Australia, currently the world's largest producer.

Table 1- Resources of lithium mining and brine deposits

Countries	**Resources (million tons)**	**Resources (%)**
Bolivia	21	20.3
Argentina	17	16.4
Chile	9	8.7
EUA	6.8	6.6
Australia	6.3	6.1
China	4.5	4.3
Congo (Kinshasa)	3	2.9
Germany	2.5	2.4
Canada	1.7	1.6
Mexico	1.7	1.6
Others	30	29.0
Total	103.5	100.0

Produced by the author from USGS data (2020).

2- Lithium Production

Concerning lithium production, Australia is the world's leading lithium producer, followed by Chile, China and Argentina. Between 2017 to 2018, Australian production of spodumene concentrates (a mineral found in granitic pegmatites with a high concentration of Lithium oxide, Li2O) tripled, mostly due to the Greenbushes mine's production, operated by a consortium composed of the Chinese company Tianqi and the American company Albemarle (LaRocca, 2020). As the world's second-largest lithium producer, Chile is also one of the pioneers in lithium production, which began in 1984. Currently, that country has two producing companies, the Chilean SQM and the American company Albemarle (Cochilco, 2020).

Chilean lithium production in 2018 amounted to 80 thousand tons/year and aimed to reach 240,000 tons in subsequent years if the planned investments materialize. SQM and Albermarle compete for world leadership in lithium carbonate production. Albemarle currently leads producing 31% of world production, followed by SQM with 21%. However, according to the Chilean company's expansion plans, which also produce lithium in Argentina, SQM is expected to become the world leader in lithium carbon production by 2022 (Reuters, 2018).

Argentina is also committed to increasing production, to go from 37 thousand tons of lithium carbonate today to 80 thousand in 2021-2022[1], due to the projects *Caucharí*, *Centenario Ratones* and *Sal de Vida*. Together, these three projects would contribute about 50 ton LCE (lithium carbonate equivalent) between the middle and the end of the decade (Cochilco, 2020).

Table 2 - Top lithium mining companies (2018)

Company name	Mining location	Mining capacity (ton LCE/y)	Market share
Albemarle	Australia, Chile, US.	73000	31%
SQM	Chile, Argentina, Australia	50000	21%
Tianqi	Australia	40000	17%
FMC	Argentina	19000	8%
Galaxy Resources	Australia	15000	6%
Jiangxi Ganfeng	Australia	11000	5%
Other	China, USA and others	33000	14%
Global production		241000	100%

Produced by the author from Sharova data (2020).

[1] According to interviews with representatives of the Argentine government conducted in November 2019.

Although Bolivia has the most significant resources globally, it has so far failed to become a lithium industry player, the country has just an artisanal production of 400 ton annually. Only Argentina and Chile have known reserves, while Bolivia has a resource, which is a less accurate estimative than reserve. A lithium brines study conducted by SRK company found that Chile's Salar de Atacama, home to what are considered the best lithium brines on earth, has a magnesium to lithium ratio of 6 to 1. In Uyuni, lithium is less concentrated with the same ratio as high as 20 to 1 (The Protocol). Given that EV batteries need a reliable, high purity supply of lithium chemicals, Bolivia's unfavorable chemistry, combined with poor infrastructure and relatively high levels of rainfall in Uyuni, help explain why its lithium chemicals are not as competitive as the lithium materials exported by Chile or Argentina.

3- Triangle Countries Mining Sector Background

Before overcoming the challenges to add value in the lithium chain, the triangle countries need to strengthen and consolidate their position as major world producers. Competition in production, which currently occurs with Australia, will happen with other countries such as Canada, Mexico, Portugal, and Germany, that have plans to advance their production.

The triangle countries have a strong mining tradition with its origins in the colonial period. Chile continues to be the world's leading producer of various mineral products and has global leadership in copper production. The intense mining presence in the Chilean and Bolivian economies is reflected in their GDP; the table below shows that mining represents around 10% of GDP in both countries. Bolivia follows with 3.6%, while Argentina has a more diversified economy where mining occupies a secondary role.

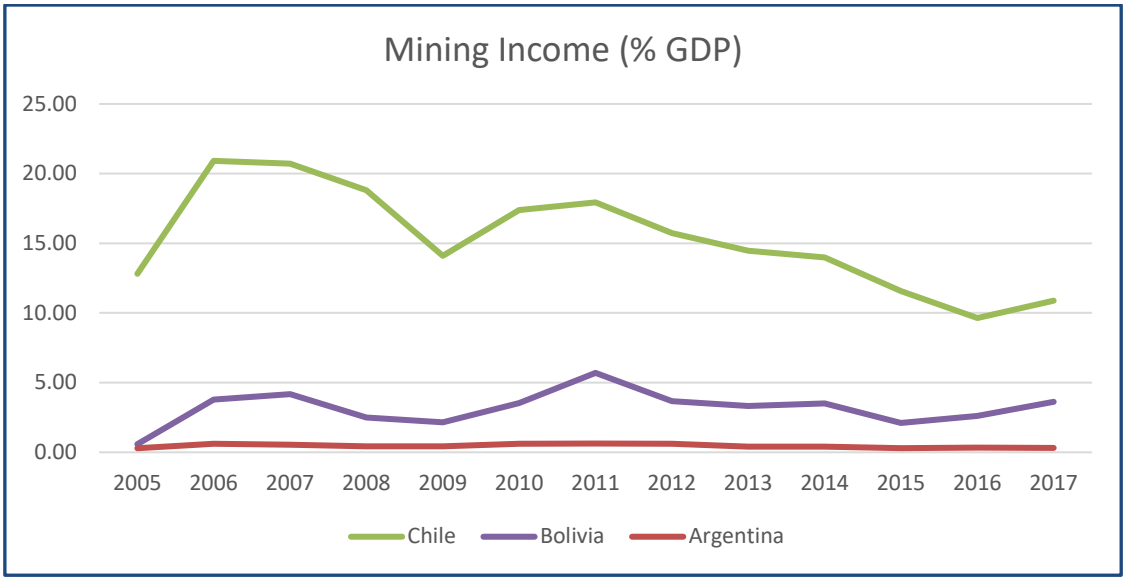


Figure 2: Mining Income - Produced by the author from World Bank data.

In general, mining investments are preceded by evaluating several factors that can be condensed into three main characteristics: stability, regulatory objectivity, and geological attractiveness. There is no doubt about the South American brines' geological attractiveness, while there is room for improvement in the remaining factors.

In this context, the Canadian institute Fraser conducts an annual survey along with mining industry executives on mining investment barriers. The institute developed the mining sector's attractiveness index that is published annually. The attractiveness index is a combination of the geologic attractiveness with government policies toward exploration investment. The Table 3 shows the results of the 2020 publication, which analyzed 76 jurisdictions. Although Chile is well located, the country dropped from its position in 2019 following the political instability that erupted in 2019 protests. The table also shows that there is room for improvement in Argentina and Bolivia. In the province of Jujuy (Argentina), interviewees point to duplications and regulatory inconsistencies. Bolivia is criticized for its political instability and selectivity in inspection with the effect of nationalizing private companies. On the other hand, Western

Australia's jurisdiction (the lithium lead producer and a direct competitor with the triangle countries) is first in the Fraser ranking.

Table 3 - Investment attractiveness index

Investment attractiveness index (2019)	Punctuation	Ranking
Chile	77.72	17/76
Argentina (Salta)	67.19	36/76
Argentina (Catamarca)	63.93	44/76
Bolivia	62.36	48/76
Argentina (Jujuy)	51.21	62/76
Western Australia	92.45	1/76

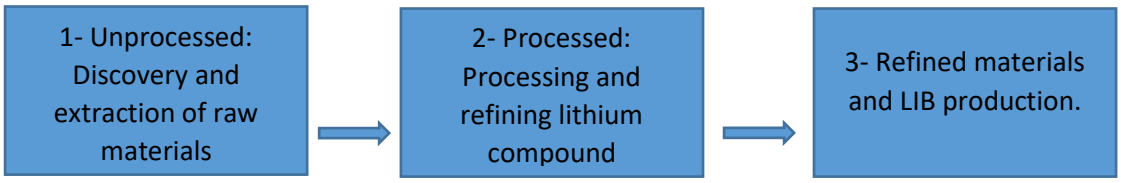
Produced by the author from Institute Fraser.

B - The Global Lithium Market

The objective of this chapter is to shed light on the lithium value chain, the global market's flows, and the lithium trade's most important features. By analyzing the Global Value Chain (GVC), which is still incipient but has been gaining strength with the penetration of EVs, it will be possible to observe that the lithium market has oligopolistic characteristics dominated not only by a few countries but also by a few companies. With the lithium chain analysis, it will be possible to conclude that if the three countries of South America are the holders of the world's lithium reserves, it can be said that China, South Korea, and Japan are the triangle countries of lithium-ion batteries (LIB). Therefore, the holders of the lithium GVC most valuable part.

1- The Lithium Value Chain

The lithium value chain begins with its extraction from rocks and brines and extends to battery manufacture. There are several proposals for dividing the lithium value chain; for this work, LaRocca's 2020 proposal published by the US International Trade Commission and summarized in 3 steps as shown in the figure below, has been adapted.



1. The processing of pegmatitic rocks produces spodumene concentrate while brines produce lithium concentrate. The brines' advantage is that the extraction process is more cost effective because lithium is dissolved in an aqueous solution. Although it is a time-consuming process, its processing is very simple, the evaporation of this aqueous solution concentrating the lithium in the remaining water. However, there are environmental implications, as the remaining water produced is unsuitable for consumption. On the other hand, the processing of pegmatites follows the traditional mining process marked by high-energy consumption.

2. In the second step, the spodumene concentrate will produce lithium hydroxide, which is the intermediate product most used in the manufacture of Lithium-Ion Batteries (LIB). Brines, on the other hand, produce lithium carbonate, which is used to produce lithium chloride and lithium metal also used in LIB production, it can produce lithium hydroxide, but it is still a costly process.

3. The last phase in this chain is also the one that concentrates the most significant added value in the lithium value chain. Actually, it consists of two stages, first the refined lithium compounds obtained from the processing of lithium hydroxide, lithium chloride, or lithium metal. And, finally, the production of lithium-Ion batteries from the refined lithium compounds.

The justification to join these two last steps into one is because the country that refines the material is the same that produces the LIB. Regardless of their high value, trade data indicates that refined lithium compounds should stay in the same country, suggesting the refined material's domestic consumption. In other words, the country that refined the material and produced the LIB is the same as the EV carmakers. The most important concentration in the value chain occurs after the commercialization of the processed material.

2- Lithium Flows

Although several countries have economically viable reserves, few use their deposits to participate in the batteries lithium Global Value Chain (GVC). Bilateral trade from Australia to China of spodumene dominated the lithium GVC in raw materials. Australia produces about 70% of the world's unprocessed material, accompanied by the EU, China, and the USA (LaRocca). Chile does not participate in this phase because its lithium carbonate is presented as a processed material or a raw material stage 2. The graph below shows that Australia's exports to China have increased in recent years, and in 2018 exceeded 90% of the Australian exports of unprocessed material.

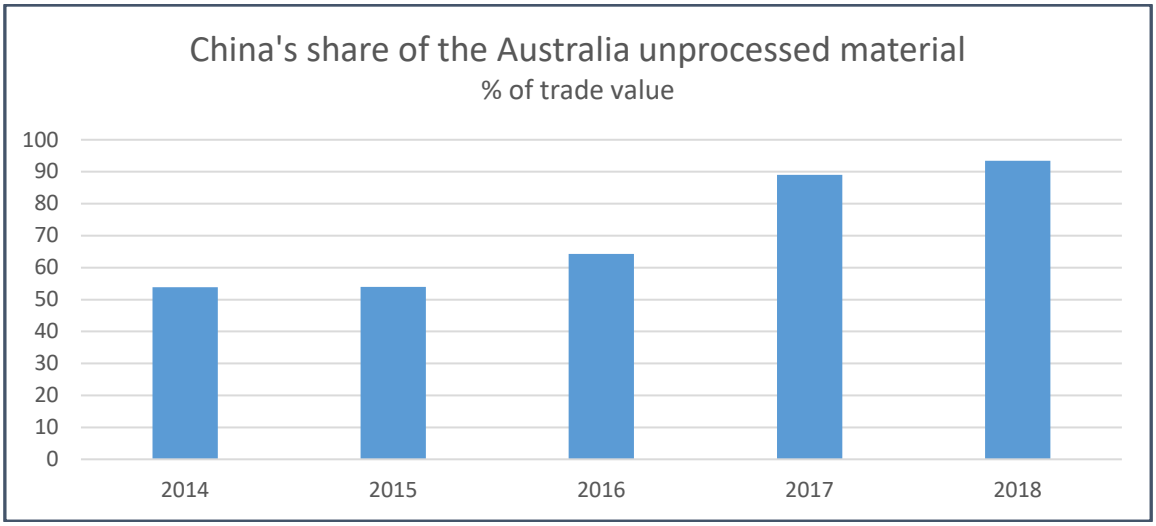


Figure 3: China's share of Australia unprocessed material - Produced by the author from LaRocca (original source: IHS Markit, 2019)

This unprocessed material exported from Australia is refined and used for the manufacture of LIB in China, and eventually, it may end up returning to Australia in EVs. Australia seeks to change this reality by developing plans to add value to its lithium production. Indeed, since December 2018, the Australian government has developed incentive policies and has attracted companies to produce lithium hydroxide within the country (LaRocca). The Australian government is also looking forward to a Trade Agreement with the USA that will exempt the lithium hydroxide tariff. The tariff raises the price of imported goods relative to domestic goods, resulting in a lower domestic price. Both tariffs and subsidies increase the price of foreign goods relative to domestic goods, which reduces imports.

With regards to the commercialization of processed material, Chile, followed by China, the USA and the EU, is the largest exporter with around 50% of the trade value in this stage, mainly in the form of lithium carbonate (LaRocca). Unlike Australia, the Chilean export destination is more diversified but still depends on the three largest global EV manufacturers, South Korea, Japan, and China.

As shown in the table below, Chile's production of raw materials in brines is based on lithium carbonate, which increased in production from 2013 to 2017 to around 90% of the total output. The production of lithium hydroxide in Chile is less than 10%.

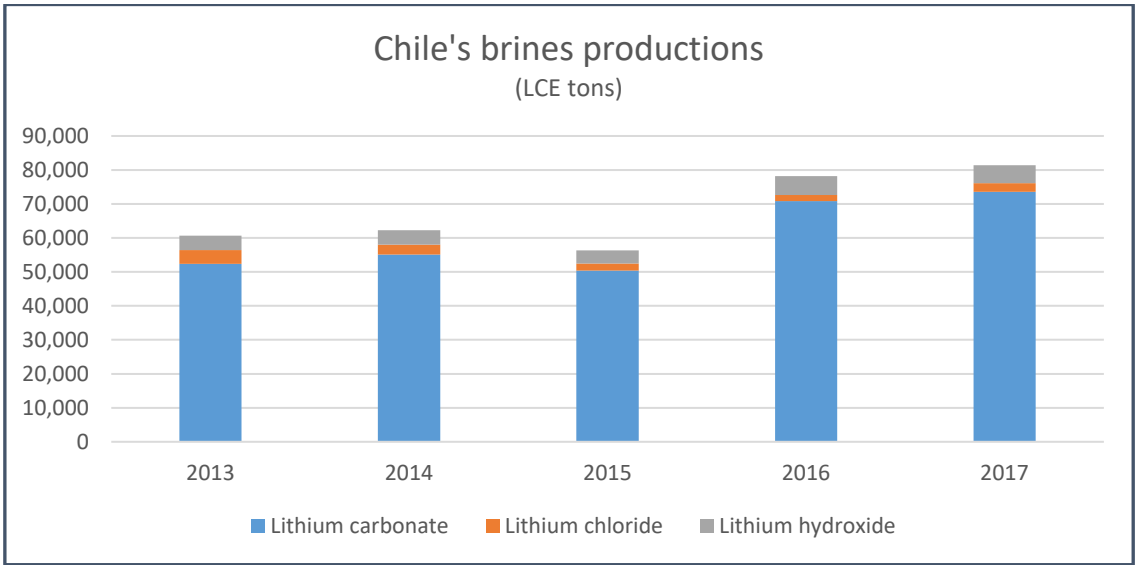


Figure 4: Chile’s brines productions - Produced by the author from USGS Minerals Yearbook data (2017)

The commercialization of spodumene concentrate by Australia or lithium carbonate from Chile are the steps where there is a robust trade flow of lithium materials for the Production of LIB. After that, the next stage of refined lithium compound does not present significant commercialization since a large part of this material remains in the same country, mainly China, South Korea and Japan, for the production of LIB. These Asian countries, and secondarily the USA and the EU, retain this market's golden share.

The LIB production market is composed of Asian companies that account for 88% of global production. This is an oligopolistic market, with the Chinese company Tianqi Lithium as a global leader. Tianqi is the largest buyer of Australian concentrate and controls 46% of the world's lithium production. In 2018 bought 24% of the Chilean company Sociedad Quimica y Minera SA (SQM) for 4 billion dollars (Quartz internet

magazine, 2018). World lithium trade is concentrated not only in a few countries but also in a few companies.

3 – A Brief Background on the Lithium Market and Demand Growth

The world's supply of lithium chemicals comes from Australia, Chile, Argentina, with a current market supply of 230,000 tons of LCE (lithium carbonate equivalent) (Equity, 2020). China is currently the world's leading importer of lithium raw materials, consuming much of the lithium produced in Chile and Argentina and importing and refining spodumene concentrate from Australia. The market for lithium chemicals, could more than triple to roughly a million tons by 2025, as the production of batteries for both EVs and renewable power grows rapidly. China, the most prominent global consumer of lithium, will need 800,000 tons of the metal per year by 2025 to support its booming electric car industry (Benchmark Mineral Intelligence).

The EVs market is growing exponentially and will demand an increase in the production of lithium products. The projection below, made by Cochilco (a technical body that advises the Chilean government), compares lithium and EV demand until 2030. Total lithium production goes from the current 300 ton of LCE to around 1800 in 2030, about six times the current production, mostly due to EV demand. Without significant investments in bringing new lithium chemical projects upstream, there might be a shortage of lithium chemicals soon as demand grows.

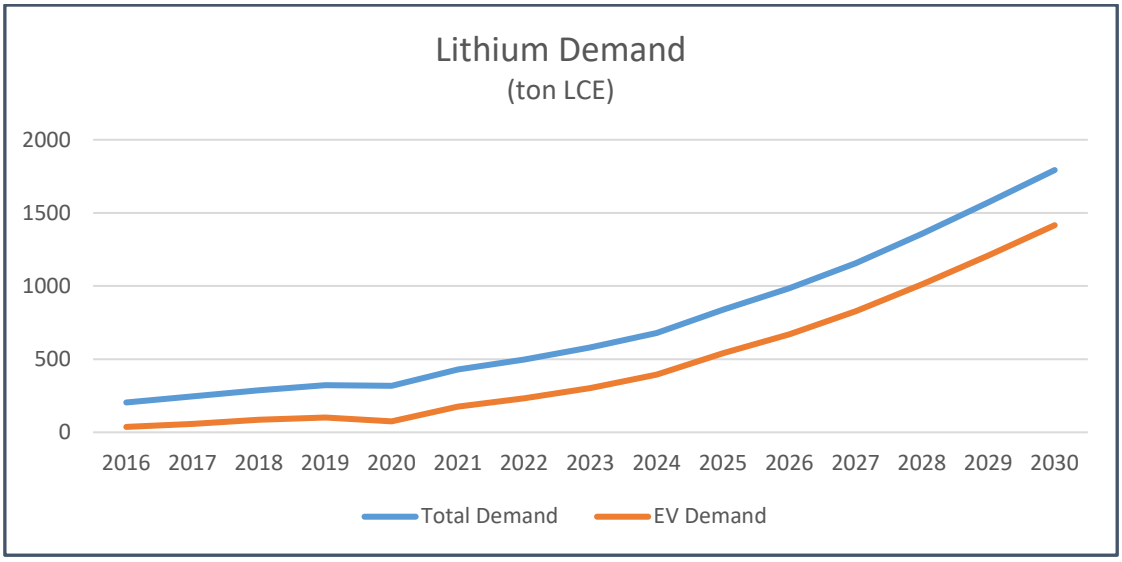


Figure 5: Lithium Demand - Produced by the author from Cochilco data, 2020.

It is still unclear what the full consequences of the COVID-19 pandemic will be, but in the short-term, the pandemic's impact is very significant with reduced sales of electric cars, which will push the lithium market prices down. It is expected that there will be delays to new projects and lower production in some current operations on the supply side. It is not yet clear about the effects of the crisis. The situation continues to be highly volatile, but there is a tendency to regularize in the long term.

There are various estimates regarding the demand for lithium with the increase of EVs. These variations occur because the projection depends on technological advancements that increase efficiency and lower battery costs, making the EV more affordable. The cost of lithium-ion batteries has dropped dramatically in recent years. In 2008, lithium-ion batteries cost $800 per kWh. Currently, the prices are around 200 US$/kWh. The industry estimates that when the prices drop to around US$100/kWh, the electric vehicle revolution will take off. In addition to that, the Paris Climate Convention's emissions reduction commitments could also increase the demand for lithium and other minerals required by a low-carbon economy. Regardless of the more or less aggressive forecasts, it is certain that there will be a significant increase in production of this

mineral. The source of uncertainty for lithium demand is in the long term due to technological advances that favor other materials.

C - Policies to Promote the Lithium Chain

This chapter aims to discuss the factors that contribute to countries' engagement in the Global Value Chain. To better contextualize this discussion, it will first analyze factors that contributed to participation in the global market. This chapter will then shed light on countries' strategies to gain more space in the lithium chain, especially China and Australia, which, together with the triangle countries, are key countries in the global lithium market.

1- Global Value Chain Determinants

According to its capabilities, each country develops a strategy to improve its participation in the global market. Although there is no standard approach, some necessary prerequisites help improve a country's position within global trade. The table below published by the 2020 World Development Report identifies four conditions at three different stages to analyze a country's integration in the Global Value Chain (GVC).

Table 4 – Global Chain Factors

<table>
<tr><th></th><th>Commodities to limited manufacturing</th><th>Advanced manufacturing and services</th><th>Innovative activities</th></tr>
<tr><td rowspan="2">Endowments</td><td colspan="3">Foreign Direct Investment: supportive investment policy and improved business climate</td></tr>
<tr><td>Labor Cost: rigid regulation</td><td>Technical Skills: education and open to foreign skills</td><td>Advanced Skills: educate for innovation and open to foreign talent</td></tr>
<tr><td rowspan="2">Market Size</td><td>Access to inputs: reduce tariffs and NTMs</td><td colspan="2">Standardization: harmonize and mutually accept standards</td></tr>
<tr><td>Market access: pursue trade agreements</td><td colspan="2">Market access: deepen trade agreements to cover investment and services</td></tr>
</table>

Geography	Trade infrastructure: invest in trade and roads	Advanced logistic services: multimodal transport infrastructure	
	Basic ICT connectivity		Advanced ICT services
Institutions	Governance: promote political stability	Governance: improve political predictability, pursue deep trade agreements	
	Standards certifications: establish conformity assessment regime	Contracts: enhance enforcement	Intellectual property rights: ensure protection

Produced by the author from WDR 2020.

For the first endowment, the ability to formulate policies to attract foreign investment and improve the business environment is essential at any stage of the GVC as most of the nations involved need foreign investment to leverage their economy. With regards to the labor market, the document points out the increase in labor force costs resulting from restrictive regulation (that makes it harder to hire part-time workers or temporary contractors for example, resulting in a less flexible labor market); and the attraction of foreigners' with specific skills in areas like mining engineering and geology (for the upstream) and engineers, chemistry and researchers (for the middle and downstream). Opportunities for foreign workers can be an important strategy at the beginning of the industry if a country does not have a workforce with the necessary skills to construct the infrastructure for the extraction and production of lithium. However, for the medium and long term like five or ten years since mining activity and the lithium industry can last several decades, the country must have a training program that includes sending nationals to world-renowned universities, a procedure adopted by several countries including China and Brazil. As a result, in a second phase, the trained native workforce would replace the foreigners' positions. Regarding this component, Argentina and Chile are economies open to foreign capital with a good educational level. In contrast, Bolivia could benefit from adopting policies to attract foreign investment such as allowing

foreign companies to work in the country without the obligation to associate with the Bolivian state-owned company (YLB) that has the monopoly of the lithium production.

The market, as a second constraint, plays a decisive role for the countries in the triangle. The standardization of the raw material produced in the brines can be a fundamental step to improving commerce for the "*lithium from the triangle*". The three countries could develop specific products according to the needs of large markets in Asia, the EU or the USA. In addition to facilitating trade, it would be a comparative advantage with Australia, which sells spodumene concentrate to China, which is an even cruder material than lithium carbonate. Improved trade agreements with South American partners, such as adding a clause in the Mercosur trade agreement for cooperation in the lithium production. It could be a decisive step for the countries in the region to foster EVs production in South America and, consequently, inducing the development of the lithium chain among the triangle countries.

As for the geographical element, an adequate road and port network is an indispensable condition for greater global market participation. Chile and Argentina have a good road infrastructure, but it could always be improved in brines' remote areas. On the other hand, Bolivia could benefit from trade agreements with these countries to facilitate its flow in production. Besides, a high-speed communication network makes a decisive contribution to better regional integration, strengthening the supply chain links with other continents. At present, geographical conditions are an obstacle to lithium chain development because the consumer market, concentrated in Asia, is very far from the countries of the triangle.

Institutional strengthening is a necessary step for the transformation of natural resources into development. However, it is important to note that regulation alone would not contribute to the country's development if the institutions responsible for its implementation were weak or deficient. Only strong institutions can guarantee the country's stability and predictability to attract investors and transform the lives of the people who own the resource. A strong institution means transparency and financial and administrative autonomy with a trained team and a body of directors with clear mandates to make decisions. Chile and Argentina have institutions that can supervise and regulate investments guaranteeing transparency and quality. On the other hand, Bolivia must seek to strengthen its institutional framework with simple, clear and transparent legislation to serve its people and not temporary governments. Public policies must have a time horizon that go beyond political mandates.

2- A briefing on countries strategies to improve Global Value Chain

China

Like any powerful country in the past, China takes advantage of other countries natural resources to formulate policies to maximize the value added by Chinese companies while supporting national strategic interests – i.e. having robust Chinese LIB and EV industries. China is currently the only country in the world that has a full lithium cycle. In the upstream sector, Chinese companies participate in the exploration of lithium carbonate in the South American brines and in the spodumene concentrate in Australia. Also, in order to mitigate its dependency on foreign materials, the Chinese government has plans to expand the native production of lithium raw materials. Regarding the downstream, the Chinese government provides incentives for EV production creating

local demand for the LIB. With these policies, the Chinese government has transformed Chinese companies, such as Tianqi Lithium and Ganfeng Lithium, into global leaders and the country is currently the world's leading EV producer.

Aware that EV production is the most important step in the lithium chain, in 2010 the Chinese government decided to classify the EV industry as one of the "strategic emerging industries", a Chinese industrialization program. In order to stimulate market adoption and technological innovation, the program, with strictly controlled subsidies, was designed by authorities of the central government. (Wu et al., 2021).

This policy is part of a structured effort by the Chinese government issued in 2012 due to the "12th Five-Year Plan for EV Development". China's government officially proposed implementing a three-step strategy for the industrialization of electric vehicles. Phase I aimed to initiate nationwide industrialization and commercialization for EVs in 25 pilot cities; Phase II seeks EV expansion to 88 cities with significant financial subsidies. Phase III aimed to promote EVs nationwide but tighten subsidies regulation. So far, China has successfully completed the first two stages (Wu et al., 2021). China is now in its 13th Five-Year Plan [2016-2020] which continues the strategy containing in its 12th plan.

It is by stimulating the demand for LIB to supply its EV industry that the entire chain is structured and feedback. Unlike several other countries that are still arguing as to whether to enter the lithium cycle or not, China has a robust domestic market that alone can guarantee their lithium market's sustainable development. The strategy is based on the high participation of Chinese companies in all stages of LIB production. The strength of Chinese power in this market is already starting to cause concern for other countries due to the concentration of the lithium cycle in just one country.

Australia

Despite having a limited domestic market with a population of 25 million people, Australia is a developed country with a strong tradition in mining. The country holds almost all of the necessary mineral elements and chemicals to develop the LIB, combined with high expertise in resource extraction, processing and innovative engineering activity (Commonwealth of Australia, 2018). The country also has a high-quality infrastructure for innovation and research, with a skilled workforce to implement and execute policies to leverage its lithium industry.

The government strategy to transform Australia into a significant processing, manufacturing and trading hub for lithium-ion batteries is similar to Chile's. It is based on offering tax offsets and exemptions on capital gains tax for investments held in the country. However, Australia also has to address its deficiencies, such as technology to convert its raw materials into lithium-ion batteries (Burton, 2018). Besides its restrictive internal market, one of the obstacles to this strategy are the agreements in force with China that import almost all of Australia's raw materials and are a global powerhouse that already have a significant scale. Another Australian strategy is based on the USA's partnership, both countries are working on a trade agreement that will exempt lithium hydroxide tariffs.

European Union

Like China, the European strategy to develop its lithium cycle is focused on the downstream with a robust production of EVs in Norway, France, and Germany. EU countries are specializing in different competencies; for example, Sweden is investing in

lithium-ion cell production, and there are plans to produce cathode facilities in Poland and Hungary (Grant et al., 2020).

Regarding the production of raw materials, only Portugal stands out as a lithium producer, but its production is aimed at the ceramics industry. Although there are important lithium reserves in Germany, Spain, and Czechia, the region does not have plans to explore its raw materials. The EU strategy is focused on the final part of the lithium cycle; the processed material needed for its EV industry comes from the Asian countries, especially China.

The USA, Canada and Mexico

Tesla, a private company dominating the EV market and with an interest in LIB for electricity energy storage markets is currently the main driver of lithium added value policies in the US. Its CEO, Elon Musk, has already expressed his intentions to verticalize its lithium chain. Still, the company relies on an agreement with Japan's Panasonic company to produce cathode and lithium cells in the short-term. Panasonic acquires its lithium-refined materials from China and the South American countries (Grant et al., 2020). The production of raw materials is not yet in its plans; intelligently, the American company prefers to benefit from competition among raw materials producing countries.

But the US EV market is not restricted to a single company since the USA is the world's second-largest producer of EVs, which raises expectations from other countries that intend to sell lithium materials to the USA. In particular, Canada and Mexico who in 2018 signed a new trade agreement with the USA to replace the North American Free Trade Agreement (NAFTA).

The first Canadian attempt to become a lithium hydroxide supplier to the emerging lithium battery market was with the Nemaska Lithium project. The company would extract the raw material from its deposit in Quebec, and the spodumene concentrate would be shipped to a lithium plant also in Quebec to transform spodumene concentrate into lithium hydroxide (from Nemaska Lithium web site). The project failed due to its remote locations and the lack of infrastructure but mostly it was due to the relative cost advantage of projects in mature lithium-producing regions such as Australia and South America.

In Sonora's northeastern Mexican state, a giant lithium deposit was discovered by the Canadian company Bacanora raising the expectation of a big lithium plant only 600 miles from Telsa headquarters in California. The Chinese company Ganfeng Lithium has already agreed to a joint venture with Bacanora to develop the mine, which will be Mexico's first. Despite the coronavirus pandemic, the company expects to begin lithium production in 2023. However, the company has yet to secure full financing for the construction of the project, which is expected to produce 35,000 tons of lithium per year (Jamasmie, 2020).

D – Policies and Chain bottlenecks in the Triangle Countries

Based on the bibliographic survey, data analysis, and publications from different sources, this chapter selected triangle countries' main difficulties in consolidating leadership in the supply of raw materials and adding value to their production. For the upstream phase, characterized by extraction and mineral processing, the main challenge is to deal with water management in the fragile ecosystems of evaporites and how to include the affected populations in the lithium projects. Regarding downstream, the

challenge is to meet the EV industry's demand for lithium hydroxide and the lack of EV production in South America, as detailed below.

1- A brief look at the Triangle countries policies

All three countries in the "lithium triangle" have strategies to develop a lithium industry to add value to their raw materials. But this is not an easy task, even for Chile, one of the most developed countries in Latin America. The country's challenge of producing lithium-ion batteries was launched by the then-president Michelle Bachelet in 2016 and reaffirmed by the current administration led by Sebastián Piñera. Negotiations were conducted in 2017 by the Chilean innovation financing agency, "*Corporación de Fomento de la Producción*" (CORFO). It established lithium at low prices to battery-makers operating in Chile. So far, the strategy has not achieved the level of success that was anticipated, and Chile continues to seek alternatives to be the first country in the region to have a LIB factory (Cochilco, 2020).

The Argentinian province of Jujuy is one of the most active in fostering alliances for battery production. Argentina has also been developing strategies to process lithium carbonate into more refined materials. The province created a brines lab, "*Centro de Investigación y Desarrollo en Materiales Avanzados y Almacenamiento de Energía de Jujuy*," dedicated to research, technological development and transfer of evaporite materials (López et al., 2019).

Bolivia is committed to public-private partnerships (PPP). In this sense, the state company *Yacimientos de Litio Bolivianos* (YLB), which controls the entire value chain of the metal, has been trying to promote joint-ventures with other companies. Bolivia has

projects under development with Indian, Chinese and German companies to promote extraction and create value-added products. The total investment could reach an amount of US $ 4 billion, but these projects are still in the pipeline. Despite the current low production of 400 LCE tons/year, plans for 2021 estimate a lithium production of 15 thousand tons/year (The Protocol, 2020).

2- Upstream - Brine's sustainability: social and environmental concerns

The Andean salt flats (located between 3,600 and 4,800 meters above sea level) have been inhabited since ancient times by indigenous peoples who derive their livelihood from llama breeding and agriculture in the few existing oases in these areas (Romero et al., 2019).

Lithium salt flats have particular characteristics that differentiate them from the operation of rock mining operations. In particular, the fact that salt flats are dynamic and fragile natural ecosystems. The environmental balance and economic sustainability can be severely affected by improper management of extraction activities. Besides, brines exploitation has potential effects on human settlements due to changes in the ecosystem generated by mining activity. Thus, a conflict arises between the short-term interest of maximizing the extraction of lithium, on the one hand, and the preservation of the living conditions of local communities in the long term (López et al., 2019).

In the Salar de Atacama's particular case, there are populations where the water supply is a constant problem. This is due to the water stress generated by the overexploitation of its sources. In response, local communities have invoked international treaties such as ILO Convention 169 on indigenous peoples' rights (González et al., 2020). Under the

auspices of "corporate social responsibility" or "shared value," negotiations have emerged between communities and companies regarding royalties agreements in exchange for social licenses to extract lithium. Yet, it is still necessary to go further considering the cultural aspects and the incorporation of communities in the project with training and qualification programs. As pointed out by Hersh in 2019, "communities are a mining project's first stakeholder. Companies that build and maintain relationships based on communication and respect are essential to a sustainable lithium future".

3- Middle and Downstream - Reasons for the failure of Chilean policies to attract investors

As mentioned in the previous chapter, Chile seeks to develop a value chain in the lithium industry by attracting cathode producers and other battery industry components. The contracts signed between CORFO and Albemarle (2016) and subsequently with SQM (2018) establish that these companies must sell a quarter of their production at preferential prices to specialized lithium producers operating in Chile.

There was a tender in 2018 where three consortia were chosen: Posco-Samsung, Sichuan Fulin Transportation Group and Molymet, but all of them withdrew their applications (Cochilco, 2020). Besides unmet supply problems, the Chilean government describes some reasons to explain the failure of this strategy:

• Location of battery and EV producers: There is already an established production chain in Northeast Asia. Consequently, the possibility that an Asian manufacturer seeks to establish itself totally or partially in Chile would mean a geographical disruption in its production chain, which would increase its costs and times.

• The type of lithium: Producers prefer lithium hydroxide over carbonate. However, Chilean manufacturing consists mainly of this second type.

The reasons alleged by the Chilean government for its strategy's failure coincide with recent publications on the subject (Larocca, 2020 and Grant et al., 2020). The consensus is that the lack of an EV market in the region makes it extremely difficult to promote the lithium chain. Besides, there is the additional factor of the low production of lithium hydroxide. The following is a brief account of these two factors.

3.1 Development of lithium hydroxide

In the current lithium market, carbonate is demanded with greater intensity than hydroxide (71% of the total compared to 24% for 2019). Still, it is expected that hydroxide will be the main demand driver until 2030 (Cochilco, 2020). The graph below shows the demand balance projection for the two products until 2030, when the hydroxide exceeds the carbonate. A growing inclination of battery manufacturers for the NCM type (Nickel-Lithium, Cobalt, Manganese) explains the increase of hydroxide production, a variety in which hydroxide is more applied than carbonate. However, it is important to note that both materials' production and consumption will continue to grow significantly.

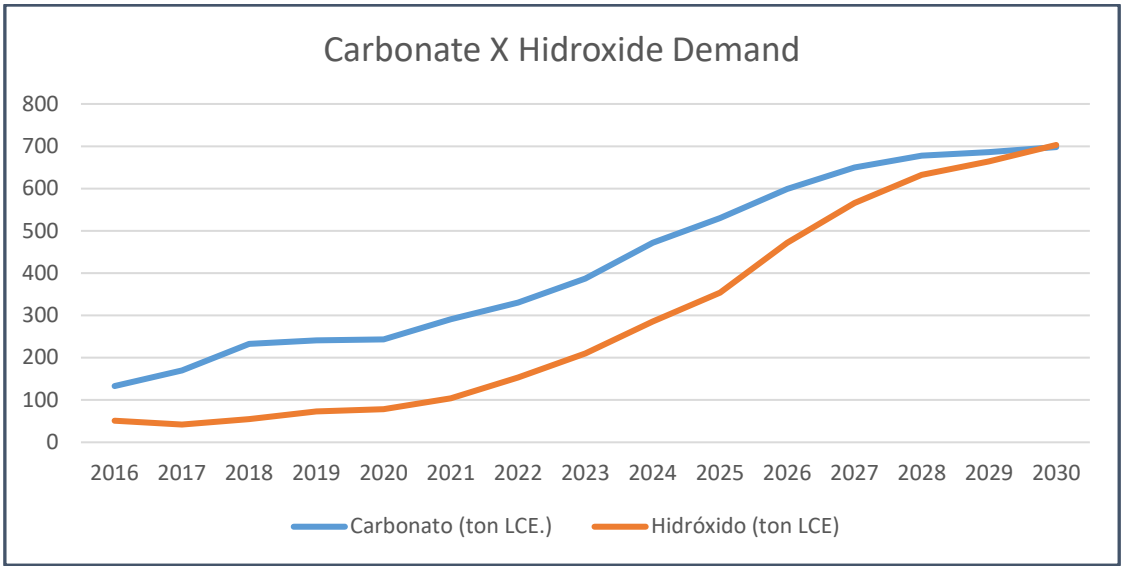


Figure 6: Carbonate X Hidroxide Demand - Produced by the author from Cochilco (2020).

Aware of the challenge, the Chilean state company SQM is developing two strategies to remain competitive. The first is to invest in research to increase the conversion of hydroxide into carbonate. The second is to invest in rocky mining projects in other countries, especially Australia, to increase its hydroxide production.

3.2 EV Market in South America

The table below shows the ranking of the main EV producers in the world. Compared with them, EV production in South American countries is practically nonexistent, discouraging investment plans for LIB's development in the region.

Table 5 - Battery electric car by country, 2019 (thousands of vehicles)

Country	2019	Ranking
China	2581.19	1
United States	882.28	2
Norway	222.62	3
France	166.81	4
Brazil	0.94	18
Chile	0.44	21

Produced by the author from International Energy Agency data, 2020.

An EV market exists when consumers are purchasing a critical mass of new battery electric vehicles. Governments should support EV transition using tax incentives and penalty-based emission standard policies (Rietmann and Lieven, 2019). The table below results from these two authors' analysis listing monetary incentives and EV (and hybrids) sales in 20 countries. The strong correlation between monetary incentives and electric car consumption leaves no doubt about the importance of government intervention in the market.

Table 6 – Monetary Incentives promoting EV sales

Countries	PHEVs and EVs sold in 2017	Total sales 2017	EV Market Share 2017	Monetary Measures
Norway	63,228	158,623	39.86%	25,000
Netherlands	9,745	414,599	2.35%	12,500
Hong Kong	4,163	39,245	10.61%	12,400
Belgium	14,885	546,533	2.72%	10,000
Canada	18,596	639,272	2.91%	10,000
United States	202,120	6,096,111	3.32%	10,000
Germany	58,299	3,442,100	1.69%	8,000
France	42,691	2,109,890	2.02%	8,000
China	601,752	24,961,948	2.41%	6,000
United Kingdom	49,387	2,539,297	1.94%	6,000
Switzerland	8,139	314,145	2.59%	5,000
Italy	5,101	1,969,140	0.26%	5,000
Japan	56,507	4,391,100	1.29%	5,000
Korea	13,943	1,495,468	0.93%	5,000
India	2,312	3,227,701	0.07%	2,355
Russia	96	1,393,400	0.01%	2,000
Taiwan	189	208,153	0.09%	2,000
Australia	2,176	915,219	0.24%	1000
Brazil	66	1,844,394	0.00%	500
South Africa	180	369,599	0.05%	0

Produced by the author from Rietmann and Lieven, 2019.

The table also makes clear the lack of incentives in Brazil for the acquisition of EVs. Brazil is the nation with the lowest market share among the 20 countries included in this analysis. Brazil's production could be a paradigm in the region because the country is a major regional car maker. More critically, Brazil has trade agreements with the three

countries in the triangle and an eventual trade agreement on lithium between them could boost EV production in the region. However, Brazil's interest in supporting EV technology is low. One of the reasons is ethanol, the country is an ethanol world leading producer, and there are lobbying groups against the introduction of EVs in the country.

Recommendations for Triangle Countries Strategic Approach

This chapter aims to outline strategies and recommendations for the triangle countries. There is no intention to exhaust the topic, the objective is to draw attention to some common characteristics that any country, and even companies, should consider to be successful, such as good planning, investing in R&D and above all, persisting.

This was true for China, that after more than 20 years of investment and strategic policies, they dominate lithium's cycle. Or the USA, which, with just two companies, won leadership in the world EV market with Tesla and leadership in producing raw materials with Albermarle.

1- Triangle Countries Lithium Institutional Body

The first recommendation to consolidate leadership in raw material supply and improve the lithium value chain is by creating an institution that unifies Argentina, Bolivia, and Chile in joining forces and seeking common solutions. Together these countries have the largest lithium reserves in the world. These geographic and geological affinities represent similar challenges that could be more successful if a supranational advisory body addressed them in an articulated and coordinated manner.

This body should define an agenda with policies for both up and downstream. Regarding the upstream, this body would design policies to increase lithium's competitiveness,

exchanging experiences of successful regulatory policies, and promoting solutions for lithium extraction that include local communities and best practices regarding the environment. Also, this organization should coordinate the development of standardized products. A recommended strategy would be a to consolidate the brand "lithium of the brines" and increase the triangle products' commercialization.

This body should also coordinate policies to add value to the lithium industry that takes advantage of each country's particular characteristics by defining short, medium, and long-term objectives.

2- Creation of environmental and social seal (seals and certification)

Changes in consumption patterns and conscious consumption are already a global reality. More than offering cheap and good quality products, the consumer wants to be informed about topics such as the attention given to the original communities affected by mining activity. In a region with a strong presence of native communities, the creation of a social seal would demonstrate compliance with Convention 169 of the International Labor Organization. It would also represent a commitment between the triangle countries and their native populations.

Regarding the environmental impact, extraction in brines has a lower impact than in traditional mining carried out in pegmatites. However, the process presents an environmental liability with a high concentration of impurities in the water that must be treated to have an appropriate destination, such as their agricultural use. In an ecosystem as extraordinary as the brine, any commitments to make brines sustainable to preserve its natural beauty and integrity must also be subject to certification and seal.

3- Triangle Countries Lithium Laboratory

Triangle countries could benefit from their geological similarities and their common challenges to create a reference laboratory. A laboratory that would invest in brine research, such as reducing water consumption and promoting water reuse; solutions to minimize extraction and production costs; solutions to increase lithium hydroxide production and finally, solutions for recycling batteries. For this purpose, an existing laboratory could be used, for example, the Jujuy Center for Research and Development in Advanced Materials and Energy Storage (CIDMEJU) in Argentina. Besides research activities, the lithium lab could also provide training and capacity building for technicians from triangle countries and seminars and lectures to promote best practices in brines. The revenue to cover the laboratory's expenses could come, among others, from contributions from the triangle countries, from regional and international development banks, in addition to contributions from countries with interests in the triangle's lithium.

4- Developing an EV market in South America

With regards to added value solutions to promote the development of batteries for EVs, there is a consensus that only with EV manufacturing actually being present in the region would it be possible to advance the lithium chain. Analysts also agree that partnerships with other jurisdictions must be made to achieve the triangle countries' goals. In this sense, fostering an alliance with Brazil, which is the leading producer and designer of vehicles in the region, to increase the production of EVs could be a decisive step towards the entire lithium chain. EV manufacturers in Brazil could establish an agreement with the TC to collaborate with LIB's development and incorporate it into their production.

This agreement could be made under the umbrella of a regional cooperation body, such as Mercosur.

Once again, it is important to have a multinational organization that brings together the three countries in the triangle to define the best strategy for the approach with other jurisdictions. The conduct of an agreement of this dimension must be very well designed to assure gains for all participants.

Conclusion

The purpose of this work was to shed light on the triangle countries' insertion in the global lithium industry. For this purpose, a vast array of material was collected and analyzed from different sources, approaching different angles of this industry and its Global Value Chain. In order to organize this work, each chapter addressed different aspects; the first dealt with the upstream sector, the second with global trade, the third with the policies and strategies, and finally with the TCs challenges.

The objective of this comprehensive and structured survey was to understand the current reality and then suggest ways and strategies to improve the involvement of the countries of the triangle in the global lithium industry. In this sense, this work did not raise new data or present mathematical models about any specific problems. Instead, it observed the lithium industry from different angles to suggest new approaches. In short, it presented new solutions to old problems.

The first approach of this work was in consolidating the triangle countries as lead producers of raw material. Although Chile and Argentina are already global players in producing raw materials and international competition will increase considerably in the coming years with lithium projects in new countries. Therefore, to continue as a lead

player, the TCs must improve water use in these fragile ecosystems and consider the affected communities from the beginning, seeking to include these populations in the generation of wealth from lithium mining. In this sense, the creation and certification of environmental and social quality seals are an important differential showing the TCs' commitment to the region's sustainable development. In addition, TCs must increase investment in R&D to increase the production of lithium hydroxide to supply both raw materials.

The second approach was on strategies to add value to lithium production. This is a more complex issue where factors such as industrialization, infrastructure, and human capital are of great importance. In addition, there is already a lithium industry established in Asia, and soon the US and EU will also enter this market. The path suggested by this work is the creation of a supranational lithium body to create synergy in TCs for the definition of policies and strategies and the establishment of partnerships with the countries of the region. With organization, strong institutions, and sound policies, it is possible to advance lithium's industrialization to produce LIB and EVs in South America.

There are no simple solutions to add value to production. Whoever wants to move forward needs to commit to a lot of work and dedication to overcome obstacles. After all, technology and innovation to sell finished products is the ambition of any nation. The most developed nations already have a strong differential, such as developed human capital and good infrastructure. But it is not impossible, especially for Chile and Argentina, which are medium-developed countries. The final message is that the path may be difficult, but it is worth trying.

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Biographical Statment

I have been working in the energy and environmental sectors for about 25 years. I am a government official of the Brazilian Government, currently on a leave of absence. For the past four years, I have been working as a Senior Consultant for the World Bank and the Inter-American Development Bank, offering my expertise in proposing strategic solutions combining sustainable development with resilience for middle and low-income countries, identifying key vulnerabilities and governmental capacity. Between 2012 and 2017, I worked on secondment at the Brazilian Presidency Office, where I handled policies and projects related to energy and climate change.

I am a Portuguese native speaker and I am fluent in both English and Spanish.

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