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The Effects of Mineral Scarcity on Lithium-ion Battery Development

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Abstract

The objective of this research is to examine how the increasing demand for lithium due to widespread use of Li-ion batteries (LIBs) and the political situation of producer countries will affect the availability of lithium for electrical applications. In the past decades the use of LIBs has increased rapidly, and this growth is driven by the development of two other big sectors, renewable energy sources and electric vehicles (EVs). Both of them are supported by the global goal of achieving a transition from fossil fuels to more sustainable solutions. In the first case, LIBs are used to provide power storage and stable power supply to off grid areas, especially in developing countries, while in the second case they are used to power the electric vehicles. This huge expected expansion creates concerns about whether the future supply will be able to follow the growth in demand. For that purpose, in this research key producer countries were analyzed as regards their reserves, supply and political situation. Moreover, the electric mobility developments were examined for the EU to get an overview of the trends of the EV sector. Finally, the global projections of supply and demand of lithium were compared. The results from the desk research displayed that some of the biggest lithium producers have a long history of political instability. On the other hand others might face much stricter mining regulation, factors that can affect the availability of lithium and create disruptions for the supply chain of lithium-based electrical application sectors. Finally, in the three scenarios comparing supply with demand, only in one projection, which is considered very optimistic to be realistic, the supply is possible to meet the demand of the lithium market.

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List of Acronyms

BEV: Battery Electric Vehicle

CO_2: Carbon Dioxide

COCHILCO: Chilean Copper Commission

EDR: Economic Demonstrated Resources

EU: European Union

EVs: Electric Vehicles

GDP: Gross Domestic Product

GHGs: Greenhouse Gases

IEA: International Energy Agency

ICEV: Internal Combustion Engine Vehicle

INDCs: Intended Nationally Determined Contributions

IRENA: International Renewable Energy Agency

Kt Li: Kilotons of Lithium Content

LCE: Lithium Carbonate Equivalent

LIBs: Lithium-ion Batteries

MCs: Mineral Commodities

PHEV: Plug-in Hybrid Electric Vehicle

RE: Renewable Energy

RES: Renewable Energy Sources

SMA: Simple Moving Averages

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

USA: United Stated of America

USD: United States Dollar

USGS: United Stated Geological Survey

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Chapter 1 – Introduction

1.1 – Background

With the Paris Agreement of 2015 on climate change, nations around the globe agreed to limit the global warming temperature under 2 ºC with further goal of 1.5 ºC. For that purpose, countries worldwide who participated in the agreement, submitted their action plans to the INDC establishing their objectives after 2020. The participants agreed to reduce their GHG emissions by following their respective plans as long as the terms are met. (Rogelj, et al., 2016). The main contributors to the GHG emissions are the transportation sector, the industry, agriculture and the power generation for electricity and heat. Approximately 40% of the emissions come from the transportation and electrical power sector. This creates the need for a transition and establishment of energy mix in these sectors, which requires the use of Lithium-ion batteries. (Diouf & Pode, 2015).

Countries in order to achieve the sustainable goals they have agreed upon, have focused on the promotion of electric vehicles and renewable energy sources. Developed countries in general when they are creating new renewable energy plants, in most cases they try to have them connected to the grid. On the other hand, in the developing ones the majority of the renewable energy plants are off grid. This means that energy storages like LIBs are needed for the supply of secure and stable electricity. (Diouf & Pode, 2015). The biggest and most demanding consumer of LIBs right now and probably in the future seems to be the EVs. It has an expected huge demand for Li-ion batteries in the decades to come and the reason for that is because the industry is trying to replace the internal combustion engine vehicles with electric ones. This movement is the result of countries' obligation to reduce drastically the emissions of GHGs and decrease pollution as much as possible. The expected number of cars worldwide for 2050 is approximately 2.5 billion and a transition to electric vehicles show great potential to achieve the sustainability goals compared with the fossil fuel ones. (Diouf & Pode, 2015).

The need for renewable energy and relief of the planet from GHGs has created the room for a market with great potential. As stated already, the two sectors with the capacity to effectively reduce GHGs and apply sustainable practices are the RES and EVs. These technologies have a great need for LIBs which is sensitive to the lithium supply. The huge demand has raised concerns about the availability of lithium and the factors that can affect its security. In general supply of raw material, like lithium, is closely related to the political situation of producer-countries, which means that the biggest producers need to be examined for that aspect. Furthermore, there are fears about whether reserves and supply will be able to cover the demand of the market or will they create disruptions to the production of these lithium based electrical applications.

1.2 – Research Question

What are the implications of rising lithium-based electrical applications in the world and whether political drivers can determine the availability of lithium for the development of Li-ion batteries?

1.3 – Research Objective and Organization

The objective of this research is to determine what are the implications of rising lithium-based electrical applications in the world and whether political drivers can determine the availability of lithium for the development of Li-ion batteries. Moreover, the political situation of key producer countries will be examined in order to better portray the current state and possible future events that might alter the conditions. The answering of the research question will be done by conducting desk research. The research is organized in four chapters as follows:

Chapter two focuses on the reserves, mining and supply of lithium. Initially, the relation between the reserves and politics will be analyzed. Moreover, the political situation of key countries will be examined and finally data will be provided to outline their reserves and supply state. In chapter three the research focuses on the lithium based electrical applications and the main consumers of Li-ion Batteries providing a projection of LIB demand in the future. In chapter four there is a market analysis of electric vehicles showing the expectations of mobility development in Europe and the barriers from the supply chain. In the end, the conclusion chapter presents the key points of the research and what knowledge has been obtained by it.

Chapter 2 – Reserves, Mining and Supply of Lithium

Since the widespread use of lithium in LIBs as the lightest metal, a concern has occurred about a possible lithium supply crisis. In the past it was predicted by scientists that by the year 2025 there would be lithium scarcity even if we recycled all the LIBs available at that time. This prediction was not taken seriously by the industry until 2015, when there was a deficit in the supply of lithium to cover the market demand at that time. After that event, the potential lithium scarcity became a topic of interest to many companies and scientists since it is closely related to the rise and development of the electric vehicle industry. Severe consultancy firms and banks started working on research about potential lithium crisis and its effects on the EVs industry. Research on this topic is of great importance for the industries that use lithium for their products and especially the technology related ones, because they need to plan their future investments and find alternatives in a worst-case scenario. (Eftekhari, 2019)

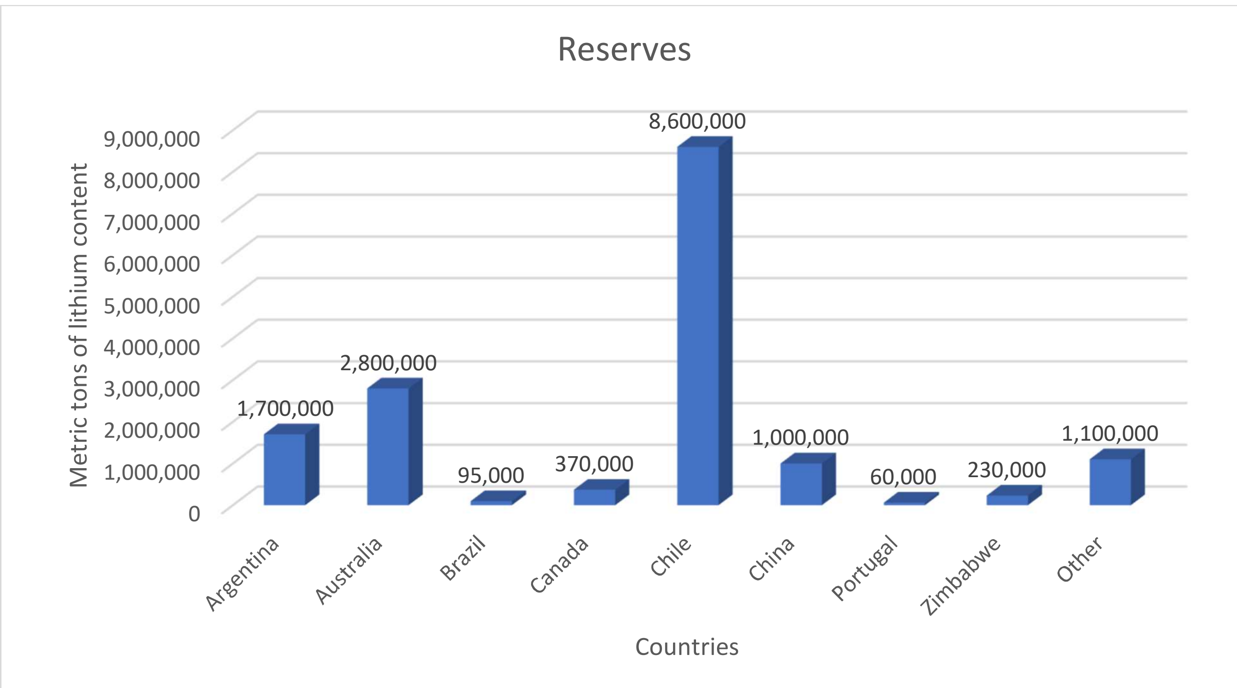

Figure 2.1: Graph of the countries with the biggest reserves of lithium. Data provided by USGS report on lithium (Jaskula, 2020).

The rise in demand for lithium requires in-depth knowledge of the demand and supply of raw materials related to lithium but also lithium itself in order to be able to adapt to possible changes. Furthermore, information about the processes and the needs of key users of lithium is required and research on potential alternatives to lithium for the industries to be prepared in case of a lithium crisis. When we are talking about a material that is mined, such as lithium, there is the need to make a distinction between the terms resources and reserves. While the known deposits are defined as resources, the proven and estimated deposits are considered to be the reserves. (Eftekhari, 2019)

According to USGS the estimated reserves that are available are around 17 million tons while the resources are way more than that number, approximately estimating to 80 million tons. (Jaskula, 2020) There are two main types of lithium deposits. These are the lithium ores which is mined from rock and the brine deposits which are distributed globally as presented in Figure 2.1. Some examples of brine deposits are the Salar de Atacama in Chile and the Salar de Uyuni in Bolivia which have 6.3 and 10.2 million tons of lithium accordingly. In the second case although the deposit is greater, the altitude is more than 3500 meters and the concentration of lithium is quite low. This makes the deposit at the moment less attractive for large scale industrial lithium production. (Eftekhari, 2019)

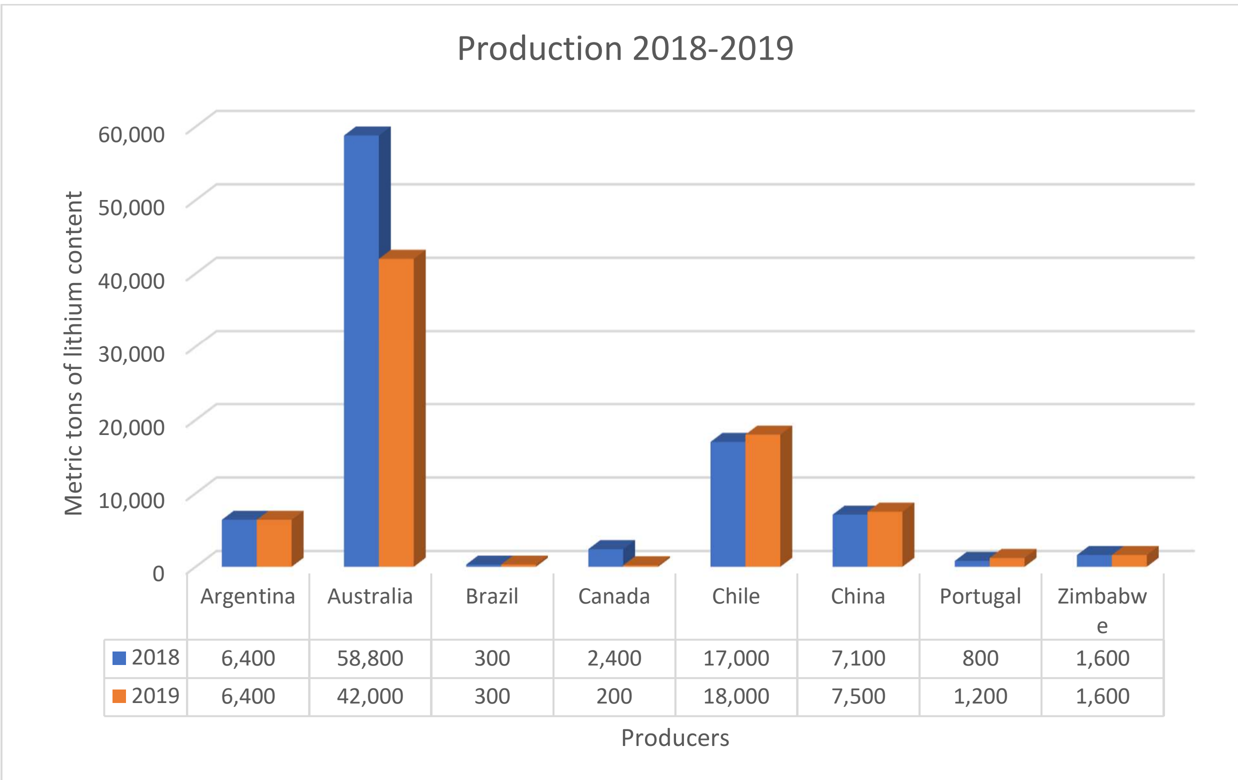

Figure 2.2: Graph showing the production for the 2018-2019 per country. Data provided by USGS report 2020 on lithium (Jaskula, 2020).

2.1 - Relation between reserves and politics

From what is mentioned above, we can realize that the main problem in the LIB industry is not the economic aspects and the reserves existing but the distribution of them in the world and the secure supply. The supply is affected mostly by the politics of the producer countries and the potential risks will be analyzed below.

The growth in demand and the limited supply create a scarcity in minerals. The factors that affect the mineral supply security are numerous. Some of these factors are the population growth, the need for economic growth and the changes in consumers' habits. The speed that the demand increases is much faster than the time it takes for the supply to adapt to the needs of the consumers because it is a very complex procedure. This imbalance has led to high prices for limited resources and to an endless competition between countries over access to these limited resources. From this situation, most vulnerable are the countries that rely their development on imports from other countries. Stating this, disruptions in the supply chain can significantly delay their growth. In some cases, the supply disruptions risks are very high because mineral deposits exist to limited number of countries and these nations can create a monopoly and put political pressure over countries that need to import the minerals. An example of such a case is the one of China, which owns 97% of the production of rare earth minerals. (de Ridder, 2013)

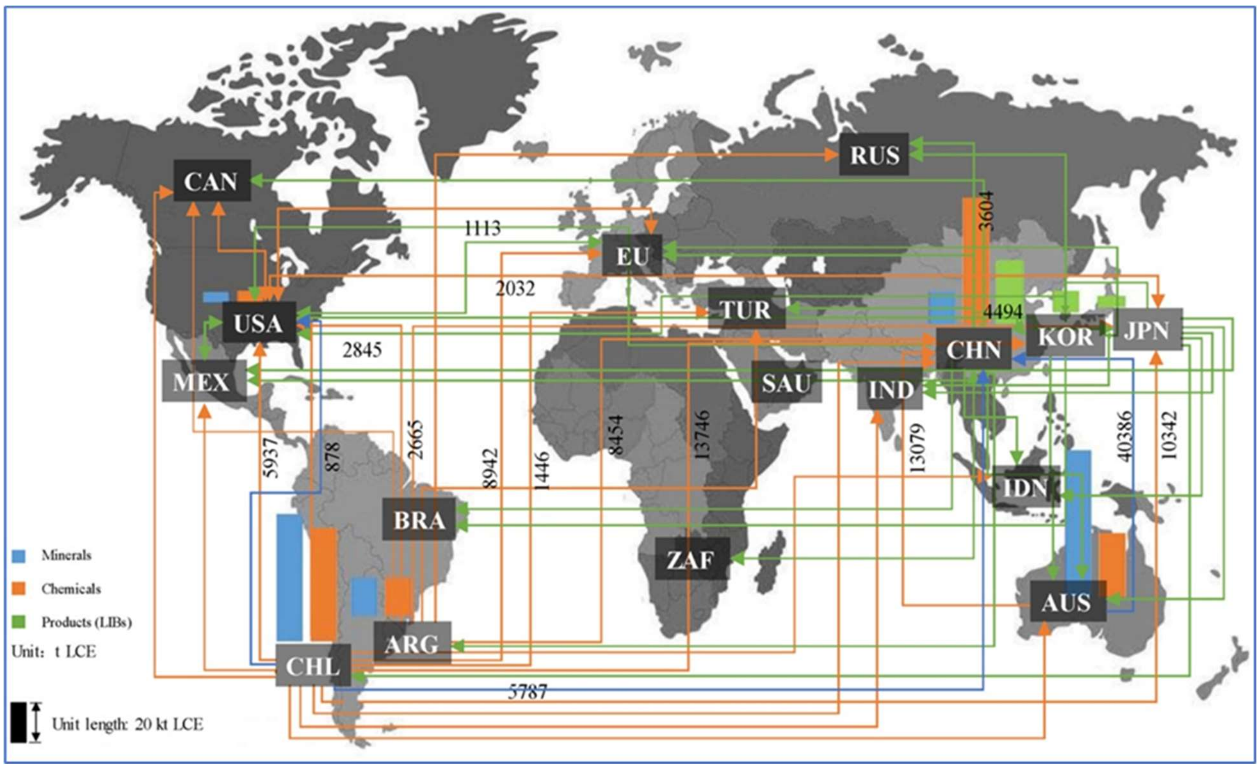

Figure 2.3: Map presenting the lithium flow from mineral to commodities. The blue line shows the beginning of the lithium supply chain. (Sun, Hao, Zhao, & Liu, 2017)

Raw materials in general face high supply risks. Especially in the case of rare earth elements monopolies, cartels and increased demand for such elements in industry can affect the occurrence of disruptions negatively. Industries like the lithium battery one and the electric vehicles have to deal with the consequences of geopolitical tension that may exist, long delivery times, shortage of raw materials and the rising prices. We realize that political risk is the main factor that determines the stability of the material supply. Political risk can be analyzed in three main subcategories. These are the political stability in the producer countries, the existing mining policy and the risk of even stricter future mining regulation. (Helbig, Bradshaw, Wietschel, Thorenz, & Tuma, 2018)

The present renewable energy trends and "green" goals set by the governments have intensified the competition over resources between the countries. From an economic perspective this leads high mineral prices and fluctuations in the prices of minerals. This instability has motivated countries to adopt a less aggressive and more friendly oriented attitude. Minerals are considered in both producer and importer countries as strategic levers and this is reflected in their policies. As a result, demand and supply of raw materials is not exclusively an economic matter regulated by the international free trade. Geopolitical matters affect the availability of minerals and sometimes tension is created by governmental interference which is shaped by international relations.

As mentioned before, the main "victims" of this instability are the mineral dependent countries and they are the ones facing the consequences which can be economic or supply disruptions. Mineral policy in the importers countries focuses on protecting the supply security because such disruptions can affect the prosperity of the country in general but also its economic growth, competitiveness and development. In some countries, securing economic growth affects also the political and social stability. Such an example is this of China, where the economic growth prevents the public opposition to the strict regime that governs.

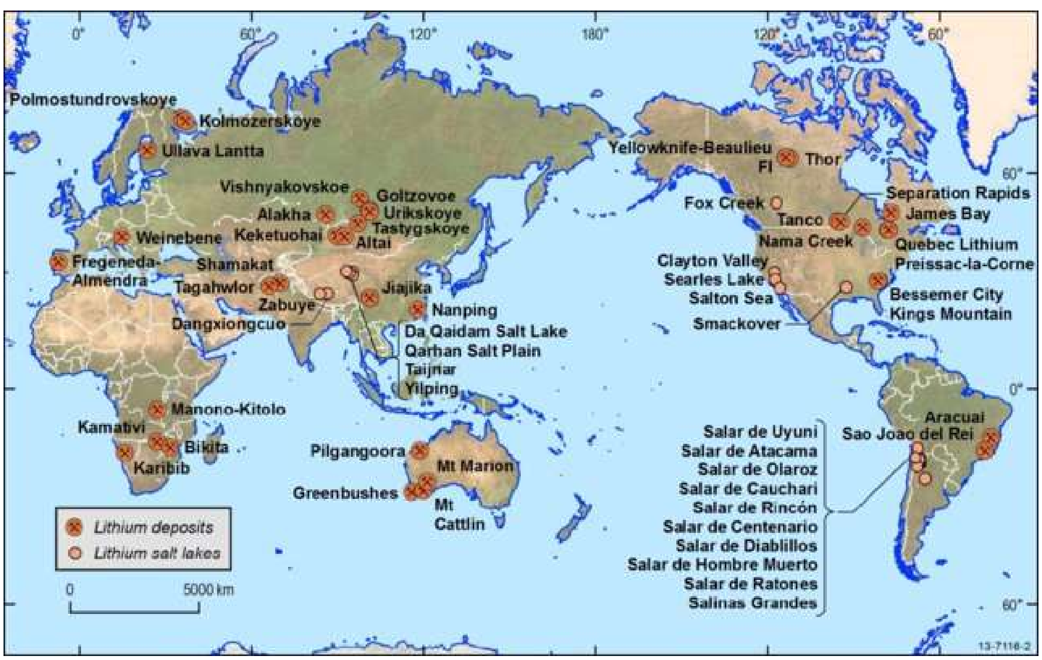

Figure 2.4: World map showing the distribution of hard-rock lithium mines (dark brown circles with symbol) and lithium-bearing salt lakes and brines (light brown circles). (Bastrakov, et al.,2013)

The way how the international mineral market works has given the leverage to the producing countries to use their resources as a mean for achieving international and domestic political objectives. This political strategy has led to the creation of resource nationalism in some countries also to the mineral sector. This resource nationalism is better known in the oil and gas sector.

Governments to producing countries are trying to limit access to foreign companies to their natural resources by adopting a domestic protectionist attitude. Such an approach can be reflected mainly in their policy which aims to make it an unattractive investment to international companies. The most common measure adopted is the increased license fees for foreigners in order to exploit the local natural resources. (de Ridder, 2013)

According to Elias, 2019 "resource nationalism can be defined as anticompetitive behaviour by individual nations, designed to restrict the international supply of a natural resource, for instance to maximize the value-added generated on their territories". The aftereffects of resource nationalism are greater on the global scale, especially with minerals that are produced in restricted number of countries. This creates a strong geopolitical leverage and provides the foundation for the creation of a monopoly or cartels between the producing countries for that specific element in order to control the global prices. (Elias T. Ayuk, 2019)

An example country that has used in the past resource nationalism is China. As we mentioned above, China has a monopoly in rare earth mineral and has used this leverage in order to settle their diplomatic incidents with mineral-dependent countries like Japan. Considering the fact that renewable energy technologies will continue to grow and so will the demand for raw materials, it is expected that mineral policies will continue focusing on securitization and politicization of rare earth minerals. The government interference and control over resource policies seems to be stronger in countries with state capitalist systems compared to market capitalist-based ones. There are cases where countries have a bottom up attitude where they take into account the needs of stakeholders such as the industry. On the other hand, there are countries that adopt a top down approach, with the government taking all the important decisions in order to achieve their diplomatic purposes and then forcing their will to industry. (de Ridder, 2013)

2.2 - Reserves data of key countries

2.2.1 – Argentina

Argentina in recent years has proved to be the most dynamic producer country of lithium, growing its share to the market from 11% to 16% in 2016. Currently the biggest projects going in the country from the production of lithium are the Salar del Hombre Muerto which has an active production since 1997 in the area of Catamarca and the other one Salar de Olaroz located Jujuy. This project was expected to reach its full production capacity in 2017. In 2016 the Olaroz project was responsible for providing 6% of the global lithium production to the market. If we take into account the four biggest active projects, the investments in the industry reached 1.5 billion USD with an annual return rate of 880 million USD from the exports. The number provided above was calculated with the average price of 8000 USD per ton of lithium in 2016.

Argentina accounts for the fourth biggest holder of proven lithium reserves worldwide. It is part of the so called “lithium triangle” together with Chile and Bolivia and this positioning might change in the future since the country has a potential of 25 to 30% of resources in the integrated area. Currently also pegmatite deposits are in the exploration stage and the country is trying to create a legal framework attractive skilled laborers and exploration. (De Litio, 2017) Argentina in 2019 produced 6,400 tons of LCE which accounts approximately for 8% of the total LCE produced in the world and its reserves are estimated at 1,700,000 tons. (Jaskula, 2020)

2.2.2 – Australia

Australia, compared to Argentina and Chile, holds a different kind of deposits. The main resources for lithium are the minerals of spodumene and lepidolite. Considering the chemistry of these minerals, they contain about 1 to 3% of Li2O and they are also associated with the mineralization of other elements such as tin and tantalum. If we analyze the geology of the area, the minerals are located in the cratons of Pilbara and Yilgarn in Western Australia aged in the Archean era and they are of granite pegmatite nature. This means that there is a significant potential in the area to discover great deposits if explored thoroughly. For the best evaluation of the brine deposits there is a need for more detailed datasets about the groundwaters of these complicated geologically speaking locations.

In 2013 a study was conducted by Geoscience Australia in order to investigate the potential for lithium and other elements in the Australian salt lakes. The research pointed out two areas, one in South Australia and one in Western Australia. These areas of interest are the Lake Frome and Yilgarn craton accordingly. These areas have a promising potential for good lithium concentration, although compared to the similar types of deposit located in South America, they are relatively low.

According to the data provided by the Proved and Probable Ore Reserves of lithium report, which was published in December of 2017, the resources were calculated to be approximately 1662 kilotons in 2016. This number represents 100% increase compared to the resources of 2015 and a 22% increase compared to 2016. This significant change in the numbers is the result of establishment of mines in the past few years. In the year 2017 the number of mines that were operating was four while another four were developing at the same time.

By the end of the same year the Economic Demonstrated Resources (EDR) amounted to about 2803 kilotons of lithium. Compared to 2015 there was an increase of 74% and the past decade because of the massive exploration activity and the successful findings, that number has increased as much as 1600%. For the same amount of time, the global increase in the EDR was about 370%.

Finally, we must take into consideration that some of the mineral resources are unavailable for economic exploitation due to current environmental policies or because of their geographical location which might be used for military activities or are parts of national parks. For that reason, we must make clear that the numbers provided as EDR in Australia, all of them belong to areas that are accessible for exploitation. (Champion, 2017) According to the estimates which were published in 2019 by the USGS, Australia accounted for owning 16% of the total world lithium reserves and 55% of global LCE production which is about 42,000 tons and the total reserves reach 2,800,000 tons. (Jaskula, 2020)

2.2.3 – Chile

Chile is a country with big lithium resources. More specifically, the national deposits are located in three areas, Antofagasta, Tarapacá and Atacama. The type of the deposit are salt flats but currently the only deposits that are being exploited are the ones of Atacama Salt flat. The reason is the quality of the deposit, since it has high concentration of lithium, potassium and borates. Furthermore, it is considered globally the best quality brine deposit. Also, it has great natural climatic conditions allowing solar evaporation which saves great energy amounts needed for the exploitation of lithium. These factors make the deposit Atacama the cheapest available lithium resource accessible to the lithium industry.

The sources where lithium can be exploited from are numerous. Some examples of deposits are in mineral rocks, brines geothermal fields etc. The subject of the available lithium resources in the world differ between the studies. For that reason, The Chilean Copper Commission (COCHILCO) conducted research and estimated according to the main publications on the topic, that the known global lithium resources are approximately 36.7 million tons. From this given number about 8 million tons are located in Chile which means that the country owns 22% of the total resources.

In general, the biggest quantity of lithium resources is located in South America and more specifically in the continental brines found in the salt flats. Other important deposits in the area are those of Uyuni salt flats in Bolivia and the Hombre Muerto in Argentina. As we mentioned above lithium can be obtained mainly from pegmatite rocks and brines. These sources, both can provide lithium carbonate which has many applications in multiple sectors. (Cochilco, 2013) Chile, in 2019 according to the research had a production of approximately 18,000 tons of LCE out of the global production of 77,000 tons LCE in the year of 2019. This means that Chile produced that year about 23% of the total LCE produced in the world. Chile also seems to be right now the country with the biggest reserves, reaching 8,600,000 tons of LCE (Jaskula, 2020)

2.2.4 – China

Although China is one of the richest countries in terms of lithium deposits, in 2013 the production accounted only for 5% of the production globally. China is the third biggest owner of lithium reserves and it is increasing its lithium production the past few years. Nonetheless 80% of it is coming from mineral mining.

In 2014 according to the publications of Ministry of Land and Resources, P.R.C. the total resources and reserves of China were 2.94 million tons of lithium while the Li2O reserves were calculated to be about 420,000 tons. These deposits are located in four areas, Sichuan, Jiangxi, Hunan and Xinjiang. In terms of LiCl reserves, the total number was 3.75 million ton, while combined with the resources the estimations reach 19.07 million tons in the locations of Qinghai, Hubei, Sichuan, Xinjiang and Tibet. Furthermore, the reserves and resources of spodumene reach 87,000 tons and are concentrated in Jiangxi, Xinjiang and Sichuan, while the calculations for lepidolite amounted to 10,000 tons in Jiangxi. (China Ministry of Land and Resources. & Bundesanstalt für Geowissenschaften und Rohstoffe, 2016)

According to the Ministry of Natural Resources P.R.C. in resources of lithium oxide were discovered in the areas Dahongliutan, Xinjiang, Jiajika and Sichuan. In the first two areas the resources were amounted to be around 2 million tons and in the last two 4.5 million tons. In Xinjiang and Qitai the discovered resourced totaled at 84.64 million and it is expected to exceed 100 million ton with further research. (Ministry of Natural Resources PRC, 2019) According to the USGS report of 2020 on lithium though the economically extractable reserves of China are around 1,000,000 tons of LCE and the production was 7,500 ton LCE which means 10% of the global production. (Jaskula, 2020)

2.2.5 – Zimbabwe

Zimbabwe according to (Vikström, Davidsson, & Höök, 2013) has four main lithium deposits. These are the Barkam, Bikita, Kamativi and Masvingo. In the first deposit, the main mineral is pegmatite while the other three are spodumene.

Lithium pegmatite deposits in Africa are known for more than a century now and can be identified in numerous locations. The most well-known though are the Bikita deposits in Zimbabwe. Because the deposit is also reached in other elements like tin, tantalum, beryllium and cesium minerals, a big part of the pegmatite has already been removed. Still today though, pegmatites, spondumene and petalite can be found in upper mid zones, while the lower mid zone of the deposit has significant concentration of lepidolite. The estimates about the resource are describing a quality deposit of 10.8 million tons and 1,4% concentration in lithium. Lithium deposits with similar characteristics have been discovered also in other areas in Zimbabwe. (Kesler, et al., 2012)

In 2019 Zimbabwe extracted 1,600 tons of LCE which compared to 2009 it is approximately 1,250 tons more of what was extracted during that year. This number accounts for 2% of the total LCE produced in 2019 and the countries reserves are approximately 230,000 tons. (Jaskula, 2020)

2.3 - Political analysis of key countries

2.3.1 – Argentina

In 1930 when the military officially broke the constitutional order, Argentina embarked on the path of political instability and frequent transitions between democracy and dictatorships. Instead of joining the path of sustainable institutional development, Argentina faced a fierce electoral fraud which almost led to the collapse of the political system and triggered the rise into governance of populist leaders, like Juan Péron. Unstable de jure and de facto institutional framework failed to promote policies focused on economic growth. Instead, its molded government-backed favoritism of powerful corporations of their interest and advocated pervasive rent-looking for rather than establishing some productive economic activity. These actions condemned Argentina to low economic growth and poor productivity for the next decades that came. (Spruk, 2019)

If we focus in general in the political instability of the geographic area of South America, we can easily realize the political instability that thrives in the continent. For example, in Latin America in general from the year 1971 until 2000, there was significant turbulence. More than 450 assassinations of politicians happened, 20 coups, over 140 guerrilla and rebellions, and 113 crises that almost brought down the governments. More specifically the most unstable country of the region was Argentina. In only four-year time between 1973 and 1976, 45 assassinations 3 revolutions and 15 riots took place in the country. (Blanco & Grier, 2009)

2.3.2 – Chile

In the 20th century, Chile was recognized for large city social movements and powerful institutionalized political actors, but after Chile's transition to democracy, the country has faced remarkable social conflict. For an extended period, social mobilizations were limited to few besides for the Mapuche conflict which took place in the south of Chile. That incident led to the revival of democracy in 1990. However, in the previous ten years Chile has come across a proliferation of controversial mobilizations. The biggest and more strong demonstrations, that were staged in essential cities, have agitated for the right of free education system or protection of the environment. These two problems are a hot topic for the media, and they have great social support. Meanwhile, outside of big city centers, other types of collective action associated with vital problems of a territorial nature have appeared. Some of the problems that occurred are related with the opposition to industrial mining projects, resistance to the installation of energy plants, and the need of the local communities to actively participate in the decision-making.

If we focus on extractivism, we can realize that there is a tendency to homogenize the particular conflicts into one, despite the fact that some of the instances of intensification of extraction might not lead to some conflict because not anymore all the conflicts end up in the same way. For instance, in Colombia the majority of the conflicts between locals and mining organizations do not happen anymore in the areas with the highest concentration of mining activity, but in the poorer places of the country that already face severe local governance issues. Furthermore, conflicts have to be divided in terms of how they orient. In the case where the conflicts are directly related to disputes over the country's resources, a few are absolute manifestations against the creation of mining and exploitation activities while others ought to do with opportunities of including local stakeholders in the negotiation process of the initial conditions set by the extractive industries. Other conflicts have to do with the economic aspects of the process and more specifically with the profit that is generated by the mining companies. Generally speaking, the conflict does not start by means of a formerly constituted set of actors that have the same beliefs, but by participants which have emerged from different conflicts and adopted specific organization and protest modalities. The collection of data related with the diversity of the participating actors is critical to figuring out the importance of these considerations. (Delamaza, Maillet, & Neira, 2017)

2.3.3 – Zimbabwe

Since 1980 when Zimbabwe became independent from the United Kingdom, it has faced numerous cycles of political instability. Zimbabwe was struggling to gain its independence since 1965, until the guerilla rebellion and the UN approval gave the opportunity for the free elections of 1979. In 1980 Robert Mugabe became the first prime minister until 1987 in the elections, and then he became the president of Zimbabwe, after the end of a violent conflict, until 2017. Initially when he was elected, he tried to promote the harmony between blacks and whites. At the same time, he was constantly in conflict with other guerilla leaders because he was struggling for power. In the past, this political figure has been accused multiple times of committing fraud in the elections and political violence. More recently, the elections that took place in 2008, were characterized by intense political violence and his government received severe criticism from the international community.

The main economic activities of Zimbabwe are related with agriculture and mining. Also, there is a strong link uniting the agriculture, mining, manufacturing and the commercial sectors. The president in 1997 attempted to take the land from white farmers and give it back to the local populations. Although this move led to the exodus of white farmers, the local black people at that time lacked the experience and the education in order to run properly such big farms. This event led to the decline of agricultural production and eventually a big hit for Zimbabwe's economy.

Mugabe's political approach led to a desperate economic situation and a tremendous poverty rate. In 2013 Zimbabwe's GDP was approximately 12.8 billion USD while the GDP per capita in the same year was about 600 USD. 72% of Zimbabwe's population in 2012 was living below the poverty line and in the same year, unemployment was between 10.7% and 95%. The number differs greatly depending on the factors that are taken into consideration. These statistics can easily help portray the picture of the country and the fact that the biggest part of the population was not part of the traditional labor force.

Zimbabwe, in general, is in a really bad state since the foundations of its infrastructure are pretty weak primarily owned to corruption and disinvestment. The reasons have made an unattractive place for direct foreign investment, which has led Zimbabwe's economy to a halt. Although the government is ambitiously planning to upgrade and improve the livelihood of its people, because of its current economic state these plans seem a bit farfetched for the time being. Corruption is still one huge issue for the country, and in the Transparency Corruption Perception Index Zimbabwe ranks as 156 out of 175 nations. (Olafsdottir, 2015)

2.3.4 – Possible future regulation changes in Australia and China

In the coming years there is a high possibility that the processes behind mining and processing of the minerals might change. Climate change has initiated a concern that affect drastically the mining sector, since the impact from the mining procedures triggers concerns in term of biodiversity and protection of the environment in general. The relatively new concerns are combined with the higher demand for energy and water since the exploitation procedures of the deposits become more and more complicated. At the same time, a movement has started in the consumers' society that demand for more sustainable production process. These factors have led mining companies and governments to reshape their business model in order to shift into a more consumer-oriented philosophy based on their preferences. They need to consider themselves also as the material providers since end user product has a complete supply chain behind it that affects the environment. In order to succeed in this upcoming new model, the mining companies will have to adapt to stricter regulation that might change in the future.

In order to promote and ensure sustainable development in the mining sector, governments will play a critical role to the new changes. For the parts that government is not able to fully control, the international community will be there to close the gaps. For example, the multilateral environmental agreements are of great importance in order to manage and mitigate properly the environmental impacts. Global policy will set the standards as regulations and policies, and the mining companies are expected to act accordingly to the new rules.

Since 2015 and the Aichi targets focusing on biodiversity that were agreed in 2011, all countries are trying to achieve sustainable development and comply with their commitments to the international community. Multiple normative implications are expected to be made especially in the mining sector that needs to adapt to the three dimensions of the sustainable development which are focus on the environment, society, and the economy. (Elias T. Ayuk, 2019)

2.4 – Conclusion

As we mentioned above not every country that is active in the EV and LIB industries are necessarily countries that have lithium reserves. This situation creates a controlling relationship between the producer countries and the consumer ones. From the data provided we can understand that the scarcity issue in the lithium supply is not by definition a raw material shortage because of the faster and higher increase of demand compared to the slower increase of supply. This gap between supply and demand occurs partially for technical reasons but also because of political risks and foul plays of producers. On one hand, how a producer country manages its diplomacy is out of jurisdiction for the consumer ones. On the other hand, some political risks that affect the supply chain can be foreseen in order to produce reliable projections for the future supply. Political risks can be divided into three different subcategories, political stability, current mining policy and stricter future mining regulation. In the examples mentioned above, we can see that some countries fall in different categories of political risks compared to others. More specifically, by analyzing the events in the first three countries (Argentina, Chile and Zimbabwe), we can see that all of them have a long history of political instability, creating insecurity for the potential future supply. On the contrary, Australia and China are countries that do not show events of political instability but their mining regulation might be subject to change in the near future and become much stricter since a more sustainable attitude is getting more and more ground around the world. This situation reveals that the supply chain of LIBs is quite fragile and therefore for the EVs, showing the need for another alternative to Li-ion Batteries.

Chapter 3 – Applications

Lithium is a metal which is used in numerous applications, especially with those that are related to the new technologies. Such technologies are the electric vehicles, wireless devices and the energy storage. The uses of lithium though do stop in technology applications only. It is used in other industries such as the glass and ceramic but also in the pharmaceutical, lubricant and aluminum. In most cases lithium cannot be replaced with another metal and for this reason the projection of demand of lithium is expected to show approximately 8-11% steady increase every year. Another reason for this increase in demand of lithium is the rise of electric vehicles industry which is growing very fast. Since 2000 in order to cover the demand for the production of batteries used in electric car batteries has led to an annual increase of 20% in lithium production. In 2015 according to Martin, 2017 35% of the total lithium consumed was by the lithium battery industry. (Martin, Rentsch, Höck, & Bertau, 2017)

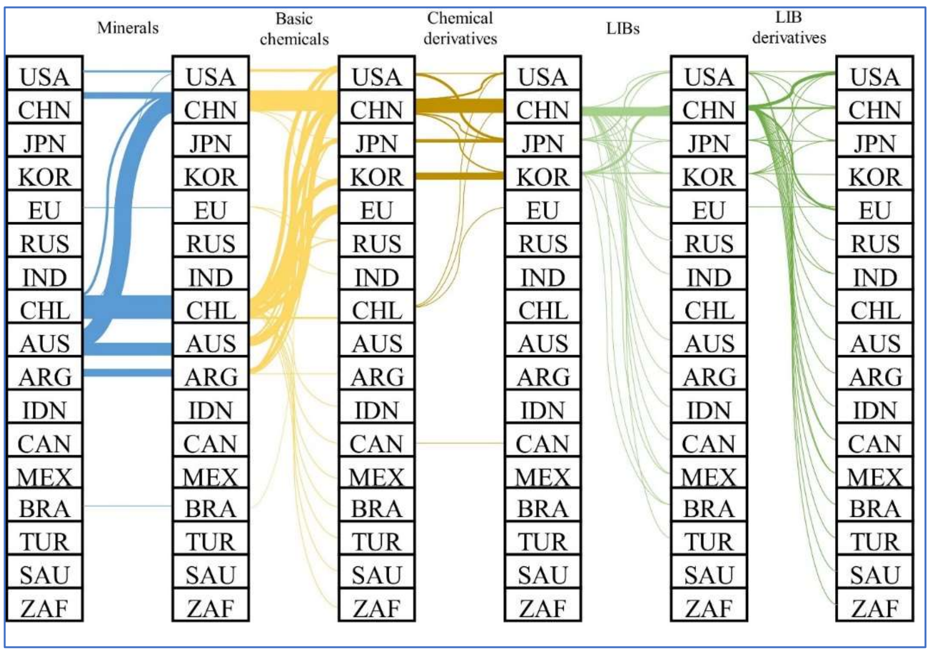

Figure 3.1: Lithium commodities flow between countries. (Sun, Hao, Zhao, & Liu, 2017)

3.1 - Applications of LIBs

Lithium ion (Li-ion) batteries have become exceedingly useful among consumer electronics. They are best known for their efficiency, their life duration, and their high volumetric and gravimetric energy. Furthermore, LIBs continuously gain popularity as electrochemical storage systems for stationary applications, including energy source for self-propelled vehicles and energy storage solutions in various applications. There are multiple battery technology options in the market, LIBs however are currently dominant regarding portable devices. Their practicality is expanding even further, as they can be also used as storage technology for renewable and automotive applications. The main difference between LIBs and nickel-cadmium (Ni-Cd) and lead-acid batteries is that specific energy and power density is higher when it comes to LIBs. (A. Stan, 2014)

Li-ion batteries are primarily used in 80% of portable electronic devices, such as mobile phones, laptops and tablets, as the remaining share consists of digital cameras, MP3 devices, video games etc. There is an annual demand of roughly 10 GWh for laptops, and it is moderately stable. However, concerning sales in units, there is a modest growth of 3.5% annually, caused by the preference towards laptops with more energy efficiency. As for mobile phones and tablets, the Li-ion battery demand is continuously growing at an average annual rate of 10%. In 2020, it is predicted that the demand for portable electronic devices will get to 45 GWh, and in 2030 to 100 GWh. (Zubi, Dufo-López, Carvalho, & Pasaoglu, 2018)

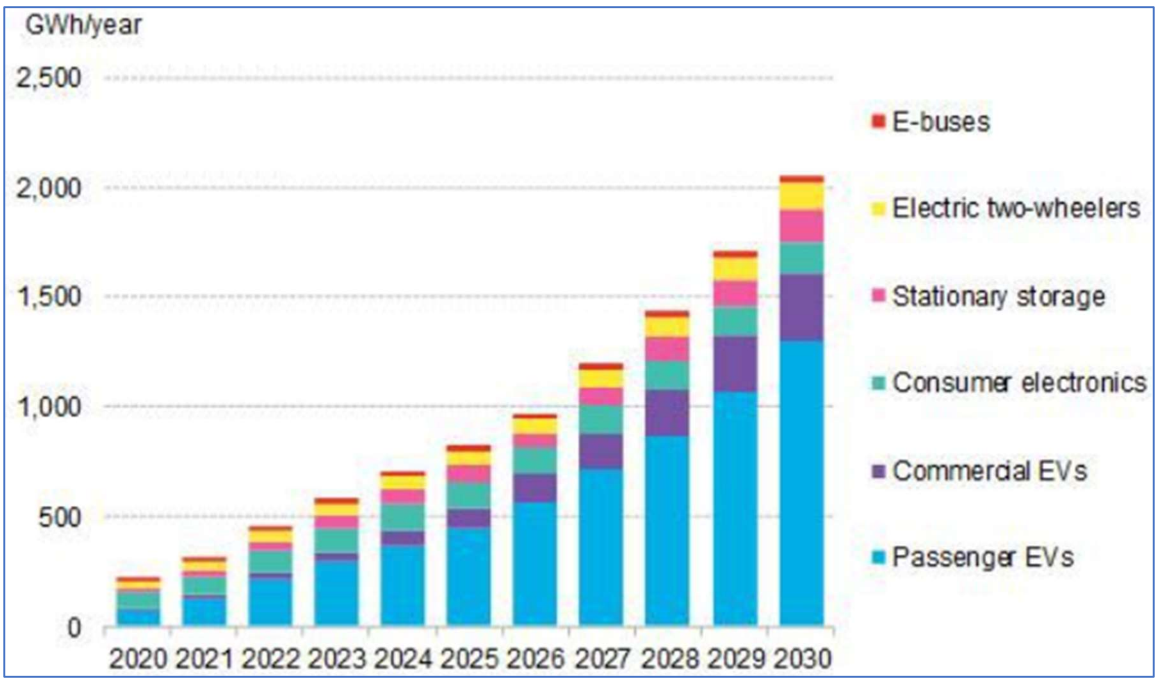

Figure 3.2: Li-ion battery demand outlook, Source BNEF 2020

3.1.1 - Renewable energy sources

According to the Renewable Energy Policy Network for 21st Century, in 2012, renewable power capacity worldwide accounted for 1470 GW. Similar statistics provided by the International Renewable Energy Agency (IRENA) reveal that worldwide capacity for end-2019 reached a total of 2.537 GW. Furthermore, IRENA estimates that by 2050, renewables installed power capacity will exceed 15.000 GW. The growing trend in renewables offers a great opportunity to shift from fossil fuels, but simultaneously raises concerns associated with grid stability and power quality.

To that end, A. Stan (2014), argues in favor of electrical energy storage, which enables the storage of renewable energy and offers enhanced flexibility with back-up power applications.

3.1.2 - Electric Vehicles

The attractive properties of Li-ion batteries, such as high energy efficiency, lack of memory effect, long lifecycle, high energy and power density, have made them the best current energy storage option for EVs. Compared to other rechargeable batteries like lead-acid, nickel-cadmium or nickel-metal hydrite, these advantages make them ideal to be smaller and lighter. However, this technology does not come without any drawbacks. The barriers are divided in two categories, performance and technological ones. In the first category the main issues are the range, lifetime of the battery and the charging rate. On the other hand, the second category includes safety and reliability issues but also the high cost for their production. These barriers are the reasons LIB's widespread adoption is still limited.

The cost of the battery and its performance are two crucial factors of the electric vehicles. The former dictates whether EVs are cost competitive compared to the internal combustion engine vehicles (ICEVs) and if they can become even more competitive in the future while the latter determines the max driving distance of an EV. According to the US department of energy, the goal for 2022 is to increase the energy density in order to achieve at least 500 km/charge (or 300 miles/charge). Moreover, the battery costs need to drop to $125/kWh. Furthermore, other than the range and the cost of the battery, the lifetime of the battery has to be increased to at least 10 years, the reliability and safety to be improved and the charging grid to expand. The widespread adoption of EVs on one hand it partially depends on technological improvements but on the other hand the government incentives can also drive the transition. Many governments provide strong support for EVs to be expanded. For example, US government funded $ 2.4 billion for the development of batteries. Moreover, the European Union invested € 43 billion in electric vehicle related research (both public and private investments), number which is expected to increase to € 225 billion in the coming years. China, which is the biggest market of electric cars worldwide, invested $ 15 billion in the industry and currently upgrading and expanding its charging grid.

The past few years more and more carmakers are focusing on developing electric vehicles. More specifically, in 2017 the three biggest German carmaker groups (BMW, Volkswagen and Daimler) invested over € 50 billion in order to develop electric cars. Furthermore, Volkswagen declared its intention to become the biggest EV maker and overtake its rival Nissan-Renault by 2025. Moreover, Mercedes Benz which belongs to Daimler group plans in a € 10 billion investment for electrification. From the battery sector, Tesla is building a Gigafactory in Nevada USA aiming to enhance the production of battery packs. After the completion of the Gigafactory, the capacity is expected to reach 150 GWh/year which is equivalent to approximately 1.5 million electric cars per year. At that time, the costs to produce battery packs made for EVs is expected by Tesla to reduce by 30%. This rapid LIB production has expanded to the transportation industry, where combined with grid uses and industrial energy storage will become a bigger market than electronic devices and consumer electronics in the future. (Ding, Cano, Yu, Lu, & Chen, 2019)

3.2 Conclusion

The Li-ion batteries have a wide range of applications. The biggest of them are the consumer electronics, the energy storage for renewable energy sources and the electric vehicles. From what is mentioned above, we can observe a future growth to all of them while some have much greater than others. This growth will be the factor driving the demand for LIBs and the main consumer will be the EVs. Electric car development is supported both from industry and the governments by multiple investments and policies supporting a transition from conventional cars to more environmentally friendly solutions. By analyzing each application growth separately and especially those with the biggest growth, will help to better understand and predict the LIBs demand and therefore the lithium one.

Chapter 4 – Market Analysis of Electric Vehicles

The European Union has set as a long-term goal of creating a competitive economy which is also at the same time low in carbon production. In order to achieve this objective, it focuses on more environmentally friendly and sustainable investments. More specifically, changes in the transportation sector such as the transition to EVs, buildings with lower energy consumption, smart electricity grids, promotion of RES with ultimate goal by 2050 to decrease at least 80% the GHG emission compared to the 1990 levels. The transportation sector is one of the most polluting ones in the European Union, so a transition to EVs could allow a significant reduction. At 2015 transportation was responsible for 23% of EU's GHG emissions and this number keeps increasing. This is happening because at large scale fossil fuels is the main energy source. (Biresselioglu, Demirbag Kaplan, & Yilmaz, 2018)

4.1 - Expectations of mobility development in Europe

EU has shown great interest in the electric vehicles and electric mobility in general and is trying to give incentives to its members. Member States on their behalf apply tax reduction for EVs and provide perks to EV owners at local, regional and national level. The Union complements efforts of this kind by supporting measures that focus on improving the transportation system, resource efficiency, fossil fuel independense, renewable sources and their use on the electrification of the transportation system. Regularly, the actions that support electric mobility are part of measures with broader nature that are aimed to the development of a sustainable transport system. (Niestadt & Bjørnåvold, 2019)

Fossil fueled vehicles still dominate the market of the EU, but the share of EVs is increasing significantly fast. Apparently, in the EU the third quarter of 2018 electric cars had a share of approximately 2% which is 30% more compared to 2017. The biggest consumers of these cars are the countries of northern and western Europe, but the largest sales growth has been observed in the eastern and southern ones. (Niestadt & Bjørnåvold, 2019)

The price of electric vehicles has been to some point an obstacle to the absolute adoption of electric vehicles. (Biresselioglu, Demirbag Kaplan, & Yilmaz, 2018). Fossil fueled cars, in general, are still cheaper compared to the purchase price of the electric ones. More specifically, on average conventional cars cost 40% less than EVs of the same category. However, the ownership of electric vehicles has proved to be lower for some models and their maintenance costs are lower because of fewer moving parts in the automobile design. (Niestadt & Bjørnåvold, 2019)

One of the most expensive parts of the EVs are the LIBs. During the past few years, even though there is higher and higher demand of lithium for the production of LIBs, the cost of the lithium batteries has reduced significantly and is expected to continue reducing in the coming years. The cost of a LIB although its reducing, it still is about 20% of the production cost of an electric vehicle. The cost of lithium in the LIBs may not be as high compared to other materials used in their production but the massive producing of EVs results in increased lithium demand and could lead to possible future scarcity. Considering that the content of lithium in a LIB is approximately 5%, an increase to the lithium price would affect the end product prices but not that significantly. (Eftekhari, 2019)

In Europe, electric car deals in 2019 grew by 50% compared to 2018, an increase rate that is essentially higher than the past year (32%). Besides, the nations with the biggest share of electric vehicles in overall car sales are located in Europe. The top two were Norway and Iceland. Norway had a share of 56% and Iceland of 22%. Within the Netherlands, the electric car share reached 15% in 2019, 9% growth from 2018 (6%). Germany outperformed Norway in 2019 for the highest deals volume at 109 000 electric cars (a 61% increase compared to 2018). France, Netherlands and UK each had sales of over 50 000 electric vehicles in 2019. The European countries showed such growth for many different reasons. 2020 is the year for the EU's CO2 emissions decrease goal. Furthermore, Germany increased the subsidies for new electric cars in February and Italy introduced measures to promote electric cars which had great impact on the market. Combined the largest car markets in the first four months of 2020 had over 145,000 electric car sales. Compared to the same period in 2019, there was an increase of 90%. For Norway though the sales for the same period stayed relatively at the same level as of 2019. (IEA, 2020)

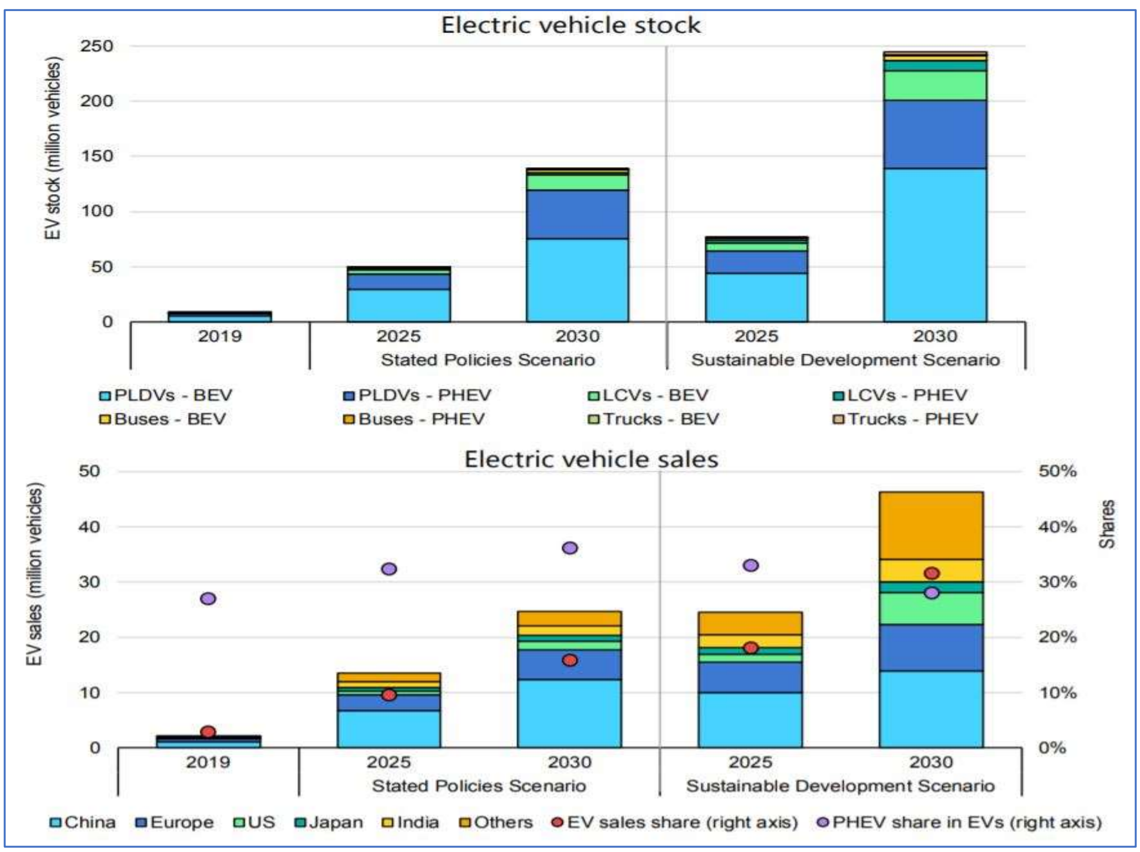

Figure 4.1: Global EV stock and sales by scenario, 2019, 2025 and 2030, Source Global EV outlook 2020.

In the report of IEA 2020 there were developed two possible scenarios in order to estimate the possible EV share and sales in 2030. These are the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario. The first one, "aims to illustrate the likely consequences of existing and announced policy measures." (IEA, 2020). The other one, aims to "ensure universal energy access for all by 2030; bring about sharp reductions in emissions of air pollutants; and meet global climate goals in line with the Paris Agreement."

According to STEPS, in 2030 the sales share of all kinds of EVs are expected to exceed 30%. In detail, electric two/three wheelers will top 40% sales share and electric buses will reach more than 50% by 2030. The targets for European Union Clean Vehicle directive are between 24%-45% for 2025 and 33% to 65% for 2030. For the commercial cars (LDVs) according to STEPS will have a market share of 30% by 2030 and 2% for electric trucks. The Sustainable Development Scenario provides only a combined projection of approximately 50% market share for all the EVs. (IEA, 2020)

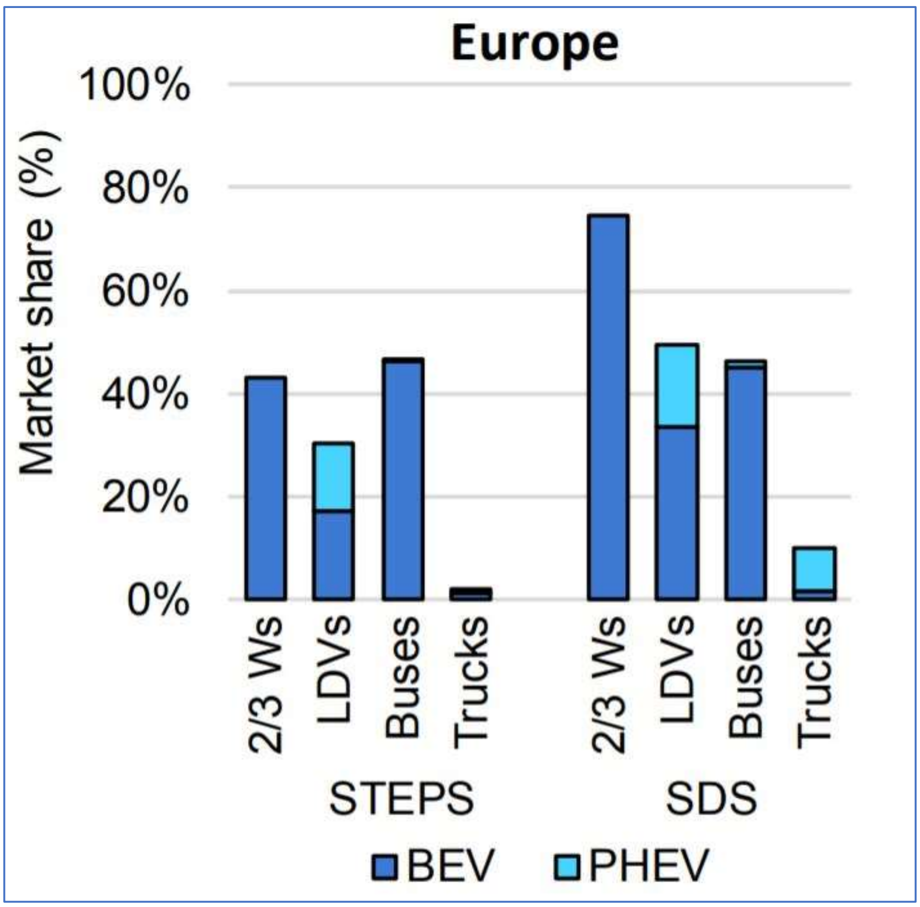

Figure 4.2: EV share of vehicle sales by mode and scenario in Europe, 2030. Source Global EV outlook 2020.

4.2 - Barriers from supply chain

Academic research questions whether the supply of lithium can meet near future demand. The principal argument against lithium availability is grounded on deposit concentration. Nonetheless the majority of studies appear positive arguing that supply will outmatch demand owed to considerable reserves. (Olivetti, Ceder, Gaustad, & Fu, 2017)

The lithium resources currently worldwide are estimated around 80 million tons while 17 million tons are considered economically extractable for the time being (Jaskula, 2020). For the period 2020 to 2030 the expected Li-ion battery market is about 2.5TWh. In terms of demand, considering the current material intensity in lithium ion batteries to be 0.16 kg/kWh, there will be needed around 400,000 tons of lithium to cover the needs of the batteries. This quantity is equivalent to 2.4% of the global economically extractable reserves. Even though these scenarios might not be critical, it is wise to not completely rely on lithium supply as virgin material. According to many studies, the best path towards sustainable development is through recycling. (Zubi, Dufo-López, Carvalho, & Pasaoglu, 2018)

Since 1995 there was a steady rise in the production of lithium globally until 2008 but then there was a decrease in the year 2009 which was signified by the beginning of the economic crisis. After that event according to Martin, 2017 the production again increased by a significant 70% in the next five years. (Martin, Rentsch, Höck, & Bertau, 2017) In the year 2016 some countries like Germany, USA and China for example, started forcing the use of electric vehicles because of the discussion of banning combustion engines by the year 2030. The combination of these events made even the optimistic scenario of expected demand to seem too low. (Eftekhari, 2019)

According to recent literature the biggest challenge for lithium production is not whether there is enough raw material available for extraction but whether supply can keep up with the rapid speeds of demand. Global demand growth for LIB sector is practically doubling every 5 years. (Zubi, Dufo-López, Carvalho, & Pasaoglu, 2018). The vast expansion of LIBs and their massive consumption the past few years that is approximately 73% from 2010 to 2014 is coupled only with 28% growth in production. This event can eventually lead to an imbalance between production and supply. Thus, concerns keep surfacing about a possible supply chain bottleneck between the beneficiated Li2CO2 and battery grade material. Nonetheless, because of the diversity of the supply and the attention to the topic industry has managed to respond relatively quickly to the disruptions. Many studies focus on lithium recycling to cover the gap between supply and demand, but this is not a solution for the near future considering the lifetime of LIBs and the stock of the batteries that are already in use. Finally, recycling of lithium is not possible economically under the current market prices which means that the near future stock will have to be mined from the ground. (Olivetti, Ceder, Gaustad, & Fu, 2017)

In the 2012 study of Mohr et.al. there were developed three different cases with the purpose to make projections between demand and supply of lithium up to the year of 2200. These scenarios were made taking into account different estimates of extractable resources. There are big deviations between the various studies on the subject. For that reason, case (a) attempts to project an underestimated scenario of the ultimately recoverable resources (URR) value by combining cumulative production and the lowest reserve or resource estimate. On the other hand, case (c) projects an overestimated URR value which combines cumulative production and the highest reserve and resource estimate available in the literature. Finally, Case (b) presents the values that according to the author are closer to reality. (Mohr, Mudd, & Giurco, 2012)

If we examine Fig 4.3 we can see that in the first two projection cases (a,b) the demand exceeds the available supply of lithium by approximately 2040. In the first “underestimated” case, the gap between supply and demand at the beginning is noticeable but after around 2080 it becomes significant. In the second case the supply still fails to cover market demand, but the gap is smaller compared to the first case. Only in the last “overestimated” scenario the supply meets the market demand and there is still room to increase the demand.

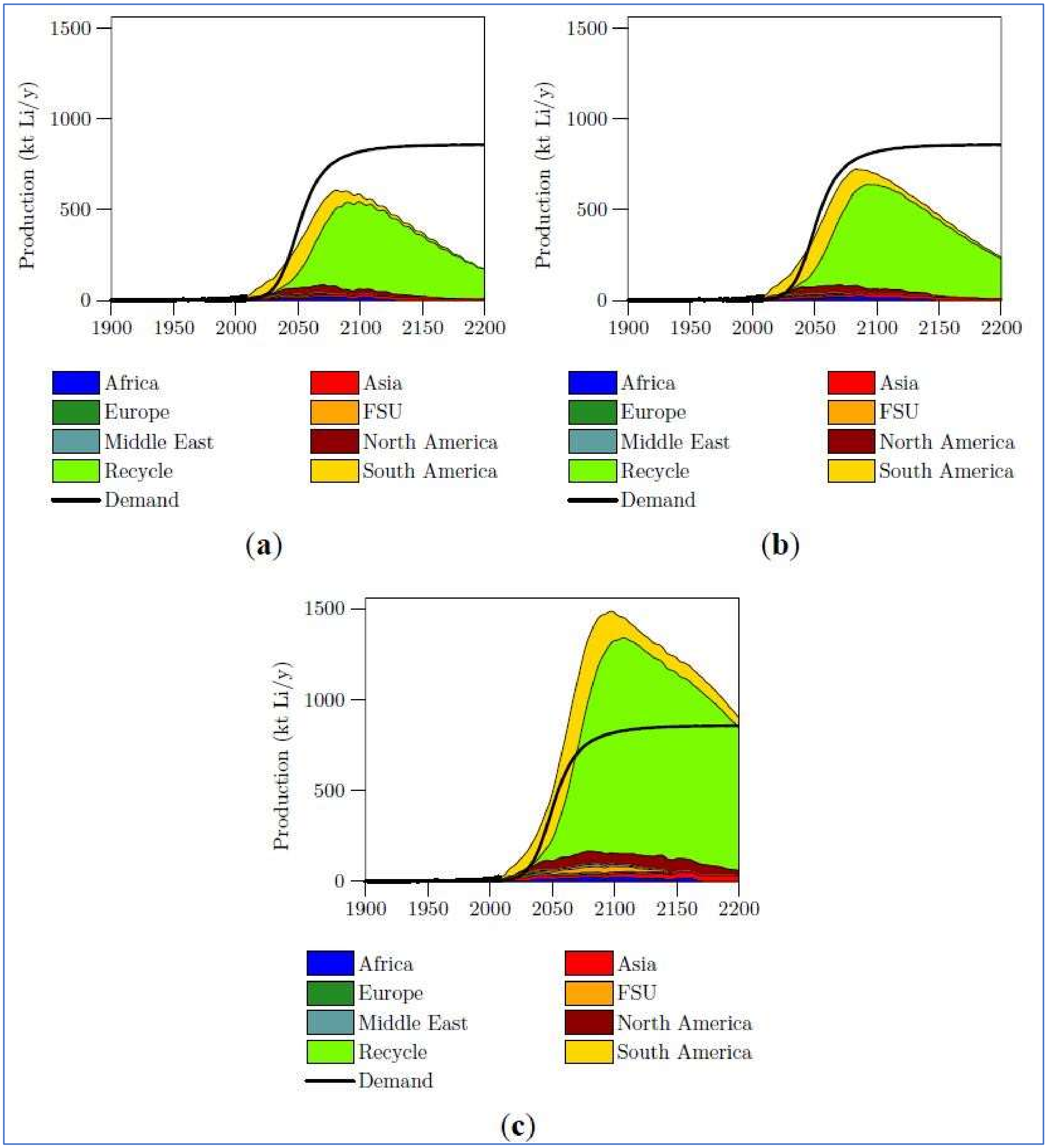

Figure 4.3: Supply projection per continent and global lithium demand, Cases a, b , c. (Mohr, Mudd, & Giurco, 2012)

4.3 – Conclusion

From the information provided above, we can realize that the market share of electric cars is still quite low compared to conventional fossil fueled cars. This situation though, is about to change in the coming decades especially in the EU since the Member States are trying to achieve their sustainable development goals by reducing their GHG emissions and become independent from fossil fuels. The high price of electric vehicles is one of the reasons that make them unattractive for consumerσ and with that in mind the European countries are taking special measures to reduce the gap between conventional cars and EVs and make them more appealing to the mass market. The projections about the future market share for EVs seem very promising and they show significant growth in the coming years. However, this very fast increase in electric cars might create problems to the supply chain of raw materials, especially those related to the LIBs like lithium. The biggest concern for the coming decades is whether the supply of lithium will be enough to cover the much faster increase of demand. Such inability could create disruptions to the supply chain and slow down the development of electric mobility. For that purpose, many studies are now focusing on finding different ways to boost the supply of lithium, such as recovery and recycle of LIBs.

Chapter 5 – Conclusion

The rising lithium-based electrical applications have created and pressing need for lithium supply in order to cover the market demand. The main driver for this increased demand is the upcoming growth in recent years of electric cars and EVs in general. The widespread adoption and development of EVs closely connected with its main component, the LIB which requires a quantity of lithium. This significant for lithium has triggered scientists worldwide to research the availability of lithium in terms of reserves and supply. From the research above considering the reserves we can conclude that the lithium reserves are found in a limited number of countries around the globe. This situation creates a monopoly environment where the producer countries can define the development of the countries in terms of lithium based electrical applications. There are examples also of countries that have used their natural resources advantage as a pressure point to achieve diplomatic goals.

At the same time, we have seen that the political situation of the producer countries can undeniably affect the availability of lithium. Many of the major reserves belong to countries where political stability has been an issue to secure for decades. Chile, Argentina, and Zimbabwe are countries with long history of political instability with events like dictatorships, revolutions and social conflicts. This situation creates the fear of whether these countries will be able to supply with lithium the market or another political event will create a bottleneck for the development of electrical applications. Furthermore, even countries like Australia and China that have achieved political stability seem to face a different kind of problem with securing stable lithium supply. The trends around the globe show a turn into more sustainable practices. For the mining industry this means much stricter regulation to come in the future compared to the existing one which might make the extraction of lithium much harder and less appealing. The five countries, that are analyzed in the research account for 84% of the global lithium reserves and 98% of the production worldwide. These numbers prove that political events on these countries can determine the availability of lithium and show how fragile the lithium supply line is.

Moreover, the growth of the electric vehicles sector has been significant compared to conventional cars and according to the research it is expected to thrive even more in the future. This creates the risk of lithium supply being unable to follow the rapid growth of the demand. As indicated in the research above, out of the three scenarios developed only the very optimistic one shows a positive projection between supply and demand. Even in this case, some scientists disagree that it displays a realistic scenario and fear that the development of EVs will face barriers of supply chain around 2040. Finally, we can see through the projections that if nothing changes, the EV industry will be forced to slow down in the future because the demand will surpass the supply. With that in mind, the further development of recycling Li-ion batteries has been proposed by researchers on the topic, hoping that it can strengthen the lithium supply or otherwise the need for a new alternative to lithium in the future.

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